Further Curing Of Lebanese Compost: Improving Quality And Stability

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Abstract: Assessment of compost quality from municipal solid waste (MSW) in a country like Lebanon, where national standards and quality assurances are still primitive, is an arduous task. Based on this fact, the present study was undertaken to determine the quality and stability of the compost produced in Ain Baal compost plant, in south Lebanon. Screened Samples were taken and divided into two categories. The first category was left without any interference as taken from the source (termed non-cured), whereas the second was further cured (termed cured). Analysis of both, the cured and non-cured samples showed a great variation based on the chemical and physical properties, metal content and stability tests. The control and enhancement of the curing period, aeration and moistening of the starting feedstock greatly improved the quality of the resulted compost. pH value, moisture content, C/N ratio and mineral nitrogen ammonia fitted the acceptable range after treatment. This fact reveals that with proper care and organization of the entire composting process, it is possible to improve the quality of the final product, and thus use it as agricultural supplements as a final objective. This report aims to demonstrate the current status of produced compost from Ain-Baal facility as well as to highlight on the possible enhancement of its quality.

Keywords: Chemical analysis, composting, cured sample, metal content, non-cured sample, physical analysis, stability tests.

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1 INTRODUCTION

MSWis the waste that is mainly produced by the household (trash and garbage), in addition to several industrial and commercial wastes similar in nature to the household ones, such as food scraps, newspapers, appliances, paint and batteries, but not medical, commercial and industrial hazardous or radioactive wastes, which are treated separately (Farrell and Jones, 2009). Meanwhile, inappropriate disposal of MSW is being considered as one of the main challenges facing the world, due to the negative impacts they have on different compartments of the surrounding environment (Taiwo, 2011). Depending on the fact that states that the highest portion of MSW is the biodegradable organic matter (Taiwo, 2011), the most preferable waste management technique for MSW is composting, which is done after sorting the recyclable and inert materials from the incoming feedstock. Composting, which is a form of recycling and a part of the integrated waste management, is defined as the biological degradation of organic matter or carbon-containing compounds by bacterial and fungal population, to form stable humus-like end products under controlled conditions (EPA, 1994). As a result of the controlled conditions, the composting procedure is performed to having its efficiency optimized, with mitigating any potential environmental deterioration, and thus the quality and the stability of the final product is enhanced. The conditions to be controlled throughout composting are temperature, oxygen ratio, moisture content, pH value, particle size distribution and nutrient level and balance (C/N ratio), all depending on the type of the raw materials being composted (Shyamala and Belagali, 2012). Mature and stabilized

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compost contributes great benefits to agricultural practices, where its application to agricultural soils provides a whole array of nutrients to the soil, decreases its acidification, increases beneficial soil organisms and reduces plant pathogens, as well as it improves the water holding capacity (Madrid et al., 2007). As for compost produced in Ain Baal compost plant, a village in south Lebanon, several parameters were investigated, and some procedures, regarding further curing the allegedly screened compost samples, were applied to study the effect of further curing agents on the final quality of the end product. The compost's main criteria that were examined during this study were metal content, physical and chemical properties. Nonetheless, stability tests were also performed to compare between the non-cured and the cured samples. The facility's compost process had many malfunctions, hence the objective of this study is to further cure some of the screened samples from the facility and investigate various parameters between the two to determine the effect of further curing on the overall quality of the final product.

2 MATERIALS AND METHODS

2.1 Study area

The solid waste treatment facility located in Ain Baal, in the TyreCaza, lies approximately 76 kilometers southwest of Beirut, holding the coordinates 33°14'26.52"N, 35°17'07.50"E and altitude 187m. The total annual precipitation in the area ranges between 600-800 mm. The facility was set to serve a population of 300,000 people at initiation. However, the project also has a projected expansion to serve 323,416 people by the year 2025. On a single working day of the facility, 150 tons of MSW are received and begin their treatment (Consulting Environmental Engineers, 2005).

2.2 Sample collection

The samples were collected from the Ain Baal compost plant. Twenty polyethylene bags of allegedly screened compost (300 Kg) were further cured (cured) in the laboratories of the Plant Biology and Environment department, Lebanese University, Faculty of Sciences, since many parameters, such as temperature, moisture content of the pile and aeration, were not optimized in the plant, and thus the composting process was not at its highest performance, resulting in the production of low quality compost (EPA, 1994). On the other hand, another identical sample of the same feedstock was left without treatment (non-cured) to compare the quality of the compost before and after treatment. During the curing phase that lasted for one month, moisture content, aeration and other factors were controlled by moistening and turning over (or mixing) of the compost pile of the collected samples. This maturation process enhances the utilization of the available nutrients by microorganisms until their activity diminishes due to nutrient depletion (Trautmann and Kransy, 1997).

2.3 Chemical, physical and metal analysis

Samples of both, the non-cured and cured compost samples, were sent to the Environment Core Laboratory (ECL) of the American University of Beirut (AUB) for chemical, physical and metal content analysis (Table 1). The physico-chemical properties of compost, at the maturation stage, are of great importance. The pH value of compost, for example, is an indicator of the process of decomposition and stabilization (Herity, 2003), moisture is a vital factor for the decomposing microorganisms on one hand (EPA, 1994), and a medium for the transport of dissolved nutrients on the other (Elango et al., 2009). The biodegradable form of total carbon (TC), i.e. total organic carbon (TOC), total organic matter (TOM) and total nitrogen represent a nutritional fraction in compost (Herity, 2003; The US Composting Council, 2001), while TOM is an indicator of the compost structure (Shyamala and Belagali,2012), C/N ratio, on the other hand, is considered as a reflection of compost completion (Woods End Laboratories, 2011). In addition, total nitrate may affect the conductivity, maturity and stability of the compost. However, high amount of ammonia in the compost are responsible for the release of unpleasant odors (Pagans et al., 2005). As for the presence of heavy metals in compost, it can adversely affect the soil and its biota by bioaccumulation of metals and its entrance in the food chain. The analyzed metals are Arsenic (As), Chromium (Cr), Copper (Cu), Lead (Pb), Mercury (Hg), Nickel (Ni), Manganese (Mn), Iron (Fe), Calcium (Ca), Potassium (K) and Phosphorus (P).

TABLE 1

LIST OF PHYSICO-CHEMICAL AND METAL ANALYSIS PERFORMED

Analysis	Method
pH	APHA 4500-H+ Electrode
Moisture Content (%)	Gravimetry
Total Carbon (%) dry weight	Thermofinnigan- High combustion
Total Organic Carbon (%) dry weight	Thermofinnigan- High combustion
Total Organic Matter (%) dry weight	By calculation= Total Organic Carbon x 1.724
Total Nitrogen (%) dry weight	Thermofinnigan- High combustion
Chlorides (mg/kg)	HACH 8225- Titration
Conductivity(mS/cm)	APHA 2510- Electrode
Mineral Nitrogen-Ammonia (mg/kg)	HACH 8039, Spectrophotometer
Mineral Nitrogen-Nitrates (mg/kg)	APHA 4500-C, Spectrophotometer

2.4 Compost Properties

2.4.1 Compost stability tests

These tests were utilized to ascertain whether the organic matter fraction of both, non-cured and cured samples, were thoroughly decomposed or not, based on different criteria (Weppen, 2002). Three different methods were used in this scope, which are jar test, self-heating test and respiration test (Trautmann and Kransy, 1997).

a) Jar test. One of the preliminary methods to detect maturity of compost is the jar test. Adequate amount of water, so that the compost is moist but not soggy, is added to a compost sample in a jar, it is later sealed for one week at room temperature. Lastly, they are opened and checked for odor.

b) Self-heating test. A sample of half-saturated compost (40-50% water) is put in a 1.5L gallon, sealed and insulated for three days. The temperature is measured before and after the experiment. The variation of the temperature is due to degradation activity of microorganisms in the sample.

c) Respiration test. This test measures the amount of carbon dioxide released from the compost sample due to the respiration of microorganisms. 25g of compost sample (adjusted to 50% moisture) and 20ml of 1M NaOH jars are put next to each other in a gallon. The CO_2 released is quantified by HCl titration of the NaOH jar the last three days of the 10 days experiment. Another gallon container is used as a blank without compost. Then calculations were done, according to Trautmann and Kransy(1997), to measure the mass of CO_2 generated.

2.4.2 Effect on soil properties

Compost is referred to as a soil amendment that helps in improving the physical and/or chemical characteristics of soil. Many claims are made about how compost enhances soil drainage and water holding capacity, so that water is available to microorganisms and plant roots. Therefore, tests for porosity and water holding capacity for compost, soil-compost mixture (25/75, 50/50 and 75/25: v/v) and soil samples (air dry) were done (Trautmann and Kransy, 1997). The soil used is a clayey loamy soil.

a) Porosity. A specific volume of each sample was tapped firmly to a cylinder. Then a volume of water was added to the same cylinder, the total volume was recorded, then the former volume was subtracted from the latter, which is the volume of the solid space. The solid space volume is subtracted from the tapped sample to get the volume of the pores. Lastly, the pore volume is divided by the tapped sample to get the porosity (%).

b) Water holding capacity. A 100ml volume of each sample was put in a funnel lined with a filter paper positioned over a beaker; then 100ml of distilled water was poured gently over the sample. The water retained (in ml) by a volume of the sample (in L) is the water holding capacity (ml/L).

2.4.3 Particle Size Distribution

Since both the porosity and water holding capacity are correlated to the particle size, this parameter was also measured using Partica Laser Scattering Particle Size

Distribution Analyzer LA-950V2 (HORIBA), in the platform of the Doctoral School of Sciences and Technology (Hadath).

3 RESULTS

3.1 Curing

The curing stage is very dependent on its period, so modification of that factor can seriously affect the outcome of compost (Pace et al., 1995). Moreover, mixing and turning increases the specific surface of the compost materials, achieves a more uniform size and homogenizes material matrix, and therefore accelerates the rate of decomposition (Guanzon and Holmer, 2003). Throughout the curing stage, which lasted for a month and where water had been added to the already screened compost along with mixing, temperature scale has witnessed 3 periods of variable values (Fig. 1). During the first few days (first period), temperature has elevated to reach its climax (65°C). Then it has started to decrease for the next 15 days (second period) to reach 55°C. The temperature has continued to gradually decrease to reach a stable temperature of 35°C at the end of the one month experiment (third period). The temperature variation revealed that non-decomposed organic matter has gotten mixed and homogenized throughout the pile, where temperature and moisture conditions are optimal for rapid decomposition (Trautmann and Kransy, 1997), indicating that the compost is still in the non-mature phase (Cabanas-Vargas et al., 2005). However, the last quarter of the month of curing showed a stable temperature, even after adding water and mixing, which is a sign of compost stability and maturity (MacGregor et al., 1981;Zhiyi, 2004).

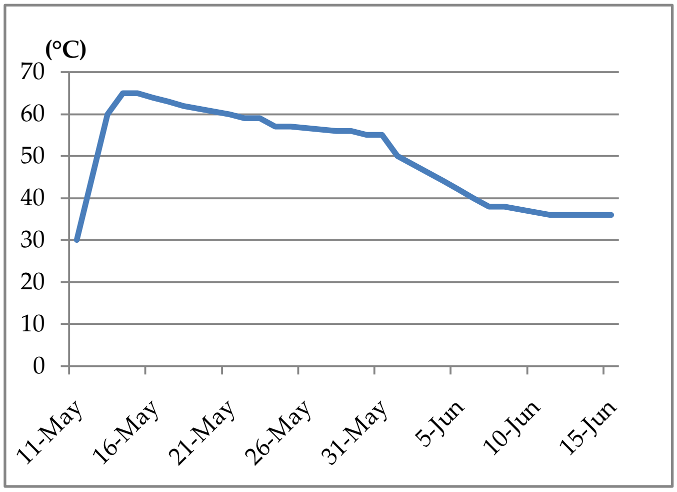

Fig.1. Temperature (°C) fluctuation during further curing

3.2 Chemical, physical and metal analysis

The results obtained in table 2 reveal a great variation regarding the parameters being investigated between the cured and the non-cured compost samples.

TABLE 2

PHYSICAL AND CHEMICAL ANALYSIS OF NON-CURED AND CURED COMPOST SAMPLES

	Compost Sample Result		
Analysis	**Non-cured**	**Cured**	**Preferred values**
pH	8.6	8.26	6.0-7.5 and not > 8.5
Moisture Content (%)	20.9	35.5	35-55
Total Carbon (TC) (%) dry weight	29.4	21.7	No absolute value
Total Organic Carbon (TOC) (%) dry weight	23.4	16.9	NA*
Total Organic Matter (TOM) (%) dry weight	40.3	29.1	30-70
Total Nitrogen (%) dry weight	1.4	1.85	1-3
C/N ratio	21	11.73	<20
Chlorides (mg/kg)	4610	3470	<500
Conductivity (mS/cm)	3.98	4.23	2-6
Mineral Nitrogen-Nitrates (mg/kg)	2000	588	240
Mineral Nitrogen-Ammonia (mg/kg)	144	32.4	<75

The pH value of the cured sample fitted in the acceptable range (Prasad and Chualain, 2003), while that of the non-cured was as high as potentially harmful to plants (Woods End Laboratories, 2011). The non-cured sample was too dry to be considered as mature, while that of the cured one lied in the preferred range (Herity, 2003). Concerning TC, TOC and TOM, there is no absolute ideal value (Herity, 2003; Helgesen, 2009); rather the values must be viewed in relation to the age and component of the material, degree of composting, nitrogen content and intended use. Nonetheless, mature compost has organic matter between 30 and 70% (The US Composting Council, 2001). TC, TOC and TOM values declined in the cured samples, from 29.4, 23.4 and 40.3 to 21.7, 16.9 and 29.1% respectively (Table 2), since organic matter and carbon is utilized by microorganisms as nutrients during the process of composting (California compost quality council, 2001). On the other hand, the total nitrogen values of both samples can be used as fertilizing complements in agriculture (Herity, 2003). Yet, C/N ratio of solely the cured sample indicates that the compost is mature (Woods End Laboratories, 2011).

TABLE 3

METAL ANALYSIS RESULTS COMPARED WITH EUROPEAN STANDARDS

		Compost sample result mg/kg		
Total Metal	**MDL* (mg/kg)**	**Non-cured sample**	**Cured sample**	**European compost standards (mg/kg)**
As	0.06	<0.06	<0.06	NLA**
Cr	0.06	69.3	75	<70 [class A+] 70 [class A] 250 [class B]
Cu	0.06	495	604	70 [class A+] 150 [class A] 400-500 [class B]
Pb	0.06	196	202	45 [class A+] 120 [class A] 200 [class B]
Hg	0.03	1	0.87	0.4 [class A+] 0.7 [class A] 3 [class B]
Ni	0.06	68	65.4	25 [class A+] 60 [class A] 100 [class B]
Mn	0.06	1900	2400	NLA
Fe	15	1500	1000	NLA
Ca	15	22000	21900	NLA
K	15	2700	2200	NLA
P	0.3	296	120	NLA

**MDL: minimum method detection limit*

***NLA: no limits applied*

Moreover, the chloride content, according to Woods End Laboratories, should not exceed 500 mg/kg. According to this range, both samples are considered out of the limit, indicating high risk for agricultural usage. Regarding conductivity, both samples showed close values, both belonging to the acceptable range (Prasad and Chualain, 2003). Mineral nitrogen-nitrate and mineral nitrogen-ammonia both decreased in high values in the process of curing, in which the values of the non-cured samples were above the acceptable limits, while those of the cured ones fit the acceptable range for ammonia (Herity, 2003; Brinton, 2000). As for the metal content of the compost samples, some tend to decrease when cured, such as Hg, Ni, Fe, Ca, K and P, others increased (Cr, Cu, Pb and Mn), while arsenic was below detection limit in both cases (Table 3), indicating harmless threat regarding this metal on the environment. The decline in the concentration of the previously mentioned metals is mainly due to their runoff in the maturation process (Fricke and Vogtmann, 1994; Delaune et al., 1999), while the increase is possibly due tothe diminution of compost mass, or the liberation of those metals when organic matter, that acts like ligands to those metal, was degraded by the microbiota(Herity, 2003; Hsu and Lo, 2000).

3.3 Compost properties

Compost stability is related to the degree to which organic matter has been stabilized during the composting process (Weppen, 2002). Most uses of compost require a stable to very stable product that will prevent nutrient tie up and maintain or enhance oxygen availability in soil or growth media (California compost quality council, 2001).

a) Jar test. After the jars were opened, the one containing the non-cured sample smelled rotten and putrid, whereas the other had a pleasant earthy odor. This different outcome between both samples can be explained by the fact that the further decomposition of organic matter had occurred in the jar containing the non-cured compost, and noxious compounds such as methane, hydrogen sulfide and organic acids were released due to the anaerobic condition of the non-cured compost jar (Brinton, 2000).

TABLE 4

CLASSES OF STABILITY FOR SELF-HEATING TEST (HERITY, 2003)

Maximum T (°C) rise over ambient	**Class of stability**	**Description of stability**	**Self-heating potential**	**Type**
0-10 °C	V	Mature to very mature Compost	Very Low	Finished
10-20 °C	IV	Curing compost	Low	Curing
20-30 °C	III	Moderately active, Immature	Medium	Active Compost
30-40 °C	II	Very active, unstable Compost	Med-High	Active Compost
40-50 °C	I	Fresh raw compost	High	Raw feedstock

b) Self-heating test.When the two containers were opened after three days, great temperature variation between both samples was observed. The non-cured and cured samples had a temperature rise of 16°C and 3°C respectively over the ambient temperature (29°C). Thus, the first is described as curing compost, while the latter as mature or finished (Table 4) (Herity, 2003).

c) Respiration test. Respiration can be used as an indicator of process performance and product stability (Herity, 2003). For 3 consecutive days, the compost stability index of both samples was calculated according to Trautmann and Kransy (1997). All three readings of the non-cured sample indicate that the compost is unstable, and thus supporting the fact that it is immature and produces high rates of CO_2, while the first two readings of the other sample indicate moderate stability, whereas the last reading indicates stable compost condition (Table 5).

TABLE 5

COMPOST STABILITY INDEX* (TRAUTMANN AND KRANSY 1997)

Time in days	Stability Index	
	Cured sample	Non-cured sample
8	8.84	19.59
9	8.84	16.32
10	4.42	19.59

carried out at a lower temperature, data interpretation using this table may be misleading (Herity, 2003).

The porosity and water holding capacity of different compost-soil mixtures were measured, and there was a great difference between the cured and non-cured samples. The results obtained are listed below (Table 6).

TABLE 6

POROSITY AND WATER HOLDING CAPACITY OF SOIL, COMPOST AND SOIL-COMPOST MIXTURE

Compost/soil mixture	Porosity (%)		Water holding capacity (ml/L)	
1 S*	44.18		350	
	Non-cured	Cured	Non-cured	Cured
0.25 C*/ 0.75 S	53.48	51.16	430	380
0.5 C/ 0.5 S	58.13	55.81	465	410
0.75 C/ 0.25 S	67.44	56.81	500	450
1 C	72	62.7	520	480

S: Soil; C: Compost

As table 6 shows, the percentage of porosity and volume of water holding capacity of the soil is the lowest among all others, indicating that compost enhances the soil's structure by increasing the porosity and water holding capacity by adding humus and organic matter (Madrid et al., 2007), which in turn will increase drought tolerance of soil. Comparing the results of both the non-cured and cured samples, the former has higher porosity and water holding capacity. The explanation for this variation is the degradation of the compost's organic matter during further curing, thus the particles' size will decrease (Fig. 2), and therefore a higher bulk density is achieved (Zhao et al., 2011). The decrease in particle size between the two samples is clearly shown in Fig 2. The maximum particle size for non-cured compost is nearly 1532μm, while that of the cured is much less (890μm). In addition, the peaks distribution of the non-cured compost sample (58.95 and 678.5μm) was of higher size than the cured one (13.24 and 77.34μm). Another variation is the higher homogeneity of the cured one.

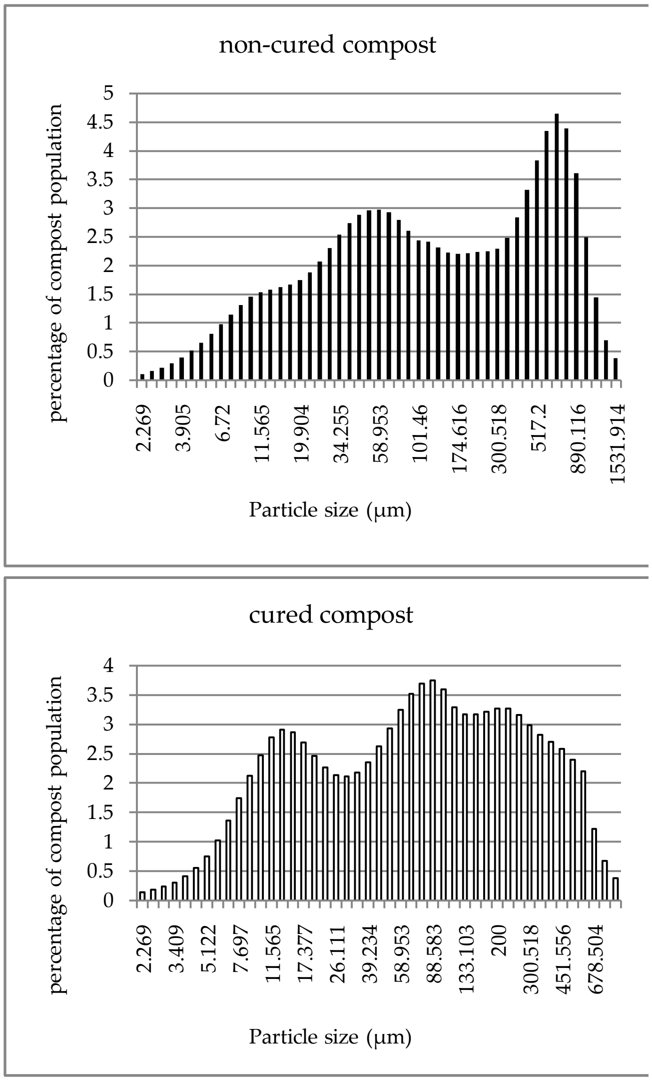

Fig.2. Percentage of distribution of particle size in cured and non-cured compost

4 DISCUSSION

The higher pH level of the non-cured sample is due to the microbial activity that leads to the production of ammonia through ammonification and mineralization of organic nitrogen; the emission of unpleasant odors is an indication of that (Sun, 2006). Moreover, such elevated values are due to unwanted components of the starting material, improper management of the composting process or even both (Helgesen, 2009). In addition, the decrease in pH in the cured sample can be attributed to the production of CO_2 from organic acids, loss of nitrogen in the form of ammonia (Lugtenberg and Kamilova, 2009) and the formation of humic-acid like substances (Garcia et al., 1991). As for the moisture content, low values are due to generated heat by biological metabolism and propelled air flow that increase the evaporation in the bioreactor (Shyamala and Belagali, 2012). The same case was recorded by (Larney and Blackshow, 2003). Moreover, a low organic matter material (30%) is considered wet at only 30 to 40% moisture (Woods End Laboratories, 2011); and this is the case of the cured sample, while the non-cured sample is too dry, thus it is difficult to incorporate into the soil because it tends to stay on the surface (Graves and Hattemer, 2000), it is also considered dusty and irritating when handled (Herity, 2003), and contains odors and possible fungal pathogens such as *Aspergillusfumigatus* (Graves and Hattemer, 2000). The decrease in the content of the carbon in the decomposing residues goes in part to the microbial biomass assimilation, its evolution as CO_2 (Cabrera et al., 2005; Fang et al., 2001), and notable further mineralization of the organic matter present in the compost (Shyamala and Belagali, 2012). This fact was also evident in the work done by Garcia et al(1991). The increase in the percentage of total nitrogen of the cured sample is due to the decomposition of the organic matter releasing the organically bound nitrogen (Shyamala and Belagali, 2012). Another explanation for the rise in nitrogen percentage during maturation phase could possibly be due to the fact that less nitrogen is being lost than carbon (Francou et al., 2005). As for C/N ratio, it should be between 10/1 and 15/1 ratio (Trautmann and Kransy, 1997), which is solely the case of the cured sample. The decrease in chlorides in the cured sample is related to the leaching of the nutrients while moistening in the curing phase (Jakobsen, 1996). While the increase in conductivity can be explained by the fact that the concentration of certain nutrients, mainly nitrate, has decreased (which is inversely proportional to electric conductivity) (Zhiyi, 2004), on the other hand, the degradation of organic matter also has a share of the salts released (Shyamala and Belagali, 2012). Normally, in mature composts, the nitrate-N levels exceed the levels of ammonium-N by several factors (Brinton, 2000), as is the case in this study (Table 2). The reason behind the decrease in nitrate concentration is its high solubility in water, so this mineral was leached out of the pile with the runoff during curing process (Aldrich and Bonhotal, 2006). There are several factors behind the loss of NH_3 by volatilization, which are aeration rate, high pH and temperature and moisture content (Sun, 2006). During the further curing period, turning and mixing were taking place, and higher aeration rates reduce the emissions of methane and nitrous oxide on one side, but augment the emission of ammonia on the other (Michel et al. 1998). Moreover, the high pH levels (>7.5), in conjunction with high temperature (>40°C), can favor considerable nitrogen loss through ammonia volatilization (Beck-Friis et al., 2003). Since ammonia is highly soluble in water, higher moisture content would help in keeping more ammonia in the liquid phase than in the gas-filled pore space of the compost (Sun, 2006), thus ammonia loss is related to the water evaporation as a consequence of temperature raise in the composting processes. This is based on the fact that the condensate collected from the moist and warm off-gas contained approximately 80% of the total ammonia lost (Sikora, et al. 1983). As the composting process proceeds, organic matter content decreases, while the concentration of water soluble heavy metals decreases. Nevertheless, the concentration of hydrophobic metals in the compost increases (Herity, 2003; Hsu and Lo 2003). The decrease in mercury can be explained by the fact that it has the highest solubility in comparison to other metals in water and is easily vaporizes into air (EPA, 2009), thus it has leached out with water during the curing stage. Although nickel element is water insoluble at 20°C and 1 bar pressure, it yet is highly soluble in the form of nickel chloride and nickel carbonate. Therefore the decrease in nickel is due to the leaching out along with chlorides (Lenntech, 2011). The jar test revealed the emission of noxious compounds such as methane, hydrogen sulfides and organic acids in the non-cured compost, and thus is not stable (Trautmann and Kransy, 1997). On the other hand, the earthy odor in the jar with cured compost is the result of the insufficient supply of readily degradable organic matter, proving the cured compost's stability. The results of the self-heating test also confirm the result of the above experiment, indicating that the organic matter is not yet fully decomposed in the non-cured sample, and the microbial population is able to increase its metabolic activity, therefore, raising the compost's temperature (Trautmann and Kransy, 1997). The high production of respiration rate (CO_2) is a consequence of the intense development of microorganisms due to the abundance of easily biodegradable compounds in the raw material (Francou et al., 2005), whereas the microbial activity is minimal in fully decomposed samples (Trautmann and Kransy, 1997). Those results accord with the two previously mentioned results.

5 CONCLUSION

The results of all the tests and experiments applied on both samples emerge several conclusions that can be inferred concerning the quality of the compost, including the physical, chemical and the metal criteria, and consequently the maturity and the stability of the final product. The general quality of the compost was improved by enhancing and controlling three factors, which are curing period, aerating and moistening. Yet other properties have shown to be negatively affected (increased metal content). This disadvantage is directly dependent on the pre-processing phase and the 14-day composting period that took place in the facility, where neither proper monitoring, nor adequate scientific and environmental analyses were applied to determine the problems occurring, and thus solving them on-site to avoid the aggravation of the problems that may occur.

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