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Composting of the organic fraction of municipal solid waste as an alternative to the uncontrolled disposal: The case of Kalamata Municipality (Greece)

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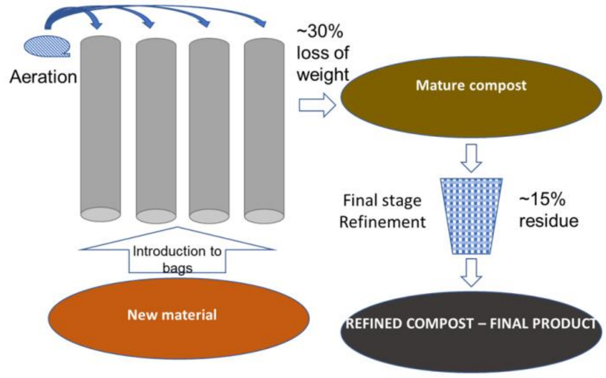
Graphical abstract



Abstract

Kalamata's decentralized waste treatment and composting scheme is a demonstration of the capacity of a municipality to manage Municipal Solid Waste (MSW) by adopting methodologies that can be supported by small-scale mobile equipment. In this study, the effort to treat MSW in the municipality of Kalamata with the minimum equipment while meeting the requirements of the law is presented. A mobile Mechanical Biological Treatment (MBT) system has been operating consisting of a sorting facility and a composting unit using closed -static aerated windrows. This paper attempts to analyze the characteristics of the proposed methodology as well as to set a framework for the optimal treatment of the Organic Fraction of Municipal Solid Waste (OFMSW) in small, decentralised units. A 3-phase scheme has been implemented (Phase 1-COLLECTION, Phase 2-COMPOSTING and Phase 3-MATURATION) where the material was placed in predefined places, in order to minimize the required area and ensure the composting process, while each composting round was optimized in 13 weeks. During the experiment, 65000 tons of MSW were treated in the MBT and 30000 tons were composted. The qualitative parameters of the composted material were monitored and found to be below the legislation limits.

Keywords: composting, municipal solid waste, recycling, waste management, organic fraction of municipal solid wastes

1. Introduction

The need for integrated municipal solid waste management in Europe has been stressed with several directives and guidance documents setting up targets and limitations. In the case of Greece, the Joint Ministerial Decision (JMD) 50910/2727/2003 was issued in conformity to the Council Directive 98/2008/EC for solid waste management. According to the legislation, the uncontrolled disposal of waste is forbidden and the deadline for the reduction of landfilling towards recycling was in 2008 and has been extended until December 2014.

In addition, Directive 99/31/EC on the landfill of wastes, sets limitations on the quantity of organic wastes disposed in landfills. The requirement of increased recovery as it is defined by the 2008/98/EU directive as well as the 4042/2012 Greek legislation, can only be met by additional treatment in order to separate and recover recyclable and biodegradable materials from the commingled stream.

The current municipal solid waste collection practice in Greece is based on a dual stream system. The mixed wastes are collected into green (or grey) bins and the recyclables (mainly packaging material and paper) into blue bins. The recyclables (glass, plastic, paper, and metal) are separated and recovered in Material Recovery Facilities (MRF) – 35 of them are in operation in Greece. The treatment of mixed solid wastes is essential, as significant amounts of recyclables are disposed in the green bins despite the operation of the dual-stream system.

The Organic Fraction of Municipal Solid Wastes (OFMSW) is separated at source or mechanically in a Mechanical Biological Treatment (MBT) system. The final product of the composting process when treated in MBTs can be characterized as Compost-Like-Output (CLO) and is subjected to legal restrictions, as it may contain impurities like heavy metals, plastics and glass. Source-separated

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biodegradable waste treated in composting units, typically in conjunction with garden wastes, can be categorized as compost (Cesaro *et al.*, 2015; Montejo *et al.*, 2015; Carabassa *et al.*, 2020).

The composting process is usually controlled by monitoring a set of parameters, whereas for the produced compost – the final product – qualitative standards have been set that differ considerably across European Member States (Cesaro *et al.*, 2015). The values of the parameters which affect the composting process (temperature, duration of the process) to eliminate the pathogens, as well as the pollutants in the final product (e.g PAHs), are set by the Greek legislation (JMD 56366/4351/2014). Moreover, it restricts the use of the produced compost from MSW (typically referred as CLO) as an inert material and not as a crop substrate.

A number of studies for MBT has been reported (Baptista *et al.*, 2011; Adani *et al.*, 2000; Lornage *et al.*, 2007; Bayard *et al.*, 2010; Połomka and Jędrczak, 2019) along with research on sorting systems (Cimpan *et al.*, 2015; Gomes *et al.*, 2008) and composting of biowaste (Cesaro *et al.*, 2015; Lopez *et al.*, 2010; Ruggieri *et al.*, 2008; Richard, 1992; Ernst, 1990) providing a valuable information on problems as well as on best practices for these treatment options.

The aim of this paper is to present a simple, as far as the infrastructure is concerned, municipal waste treatment scheme for the Municipality of Kalamata, Greece which operated for 3 years. It includes a mobile MBT system that consists of a MRF and a Composting Unit used to minimize the residues and to maximize the recovery until the municipality secures the funding to build a permanent infrastructure. The composting process was monitored and evaluated with measurements of the operating parameters and the qualitative and physicochemical characteristics of the produced CLO. The proposed management scheme met the targets set by the local integrated MSW management plan.

2. Materials and methods

2.1. Study area and MSW management

Kalamata is located in Peloponnese peninsula in Southern Greece, with a population of 69849 (Hellenic Statistical Authority, 2012). The total annual waste production has been estimated approx. 33000 tons and increases significantly during summer, due to tourism and increase in the population.

The waste composition in the region of Peloponnese according to the Decentralized Waste Management Plan of Kalamata Municipality - DWMPK is presented in Table 1, while the waste production for the period 2012-2014 is presented in Table 2 (Municipality of Kalamata, 2016).

The recyclable materials are collected in the blue bins whereas the OFMSW and residues are collected in green (or grey) bins. The content of the blue bin is treated in the Material Recovery Facility (MRF) of Kalamata, while the content of the green bin is treated in the mobile Mechanical Biological Treatment (MBT) Unit located in Maratholaka area, 10 Km from Kalamata center.

Table 1. Waste composition (Municipality of Kalamata, 2016)

Materials	Percentage % (National, 2015)	Percentage % (Peloponnese, 2010)
Biowastes	44,3	41,0
Paper/cardboard	22,2	29,0
Plastics	13,9	14,0
Metals	3,9	3,5
Glass	4,3	3,5
Other	11,4	9,0
Total	100,0	100,0

Table 2. Waste production for the period 2012-2014 (Municipality of Kalamata, 2016)

Year	Green bin (tons)	Blue bin (tons)	Total (tons)
2012	32597,65	4333,2	35369,66
2013	27614,48	4476,77	30409,07
2014	29899,91	4953,53	32893,13

The treatment process in the mobile MBT comprises the following steps:

1. Collected materials from the green bins are mechanically separated into two streams: the biodegradables and the non-biodegradables
2. Recyclable materials are recovered from the non-biodegradables stream
3. The biodegradable fraction is driven to the composting unit
4. The composted material is refined by sieving (15mm)
5. The residues (non-biodegradable and non-recyclable materials) are baled and stored on site.

The mobile MBT is presented schematically in Figure 1 and consists of a bag opener (shredder) with a capacity of 8tn/h, a rotary sieve for organic fraction separation (drum diameter of 1400 mm and a length of 3800 mm, hole size 80mm), a sorting table for handpicking of nonferrous and plastic materials (5000 mm length and 1100 mm width), a magnet for the ferrous materials and a ball press machine for the residues. A photo of the facility is displayed in Figure 2.

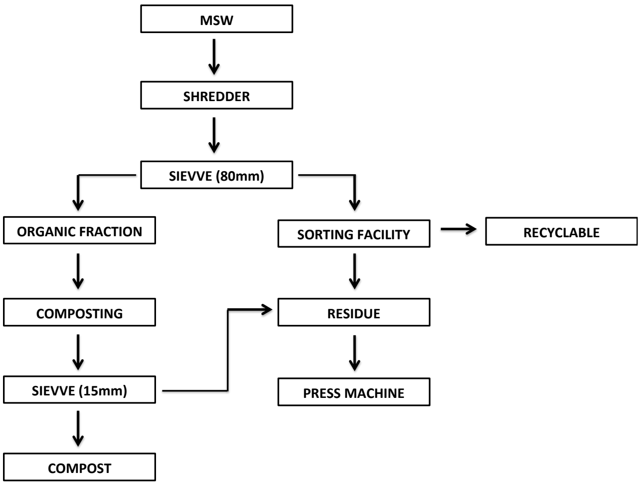

Figure 1. Schematic representation of the mobile MBT in Kalamata.

Figure 2. Mobile MBT facility in Kalamata, Greece.

The project began in November 2013 and until January 2015 over 65000 tons of MSW were treated out of which approximately 30000 tons were organic wastes. The 2014 annual waste production was 32893,13 tons out of which 3880 tons were recyclables (plastic, metals and aluminium), while approximately 19000 tons of biodegradable wastes were composted.

2.2. Description of the composting process

Closed static aerated windrows were formed using big plastic bags (60 meters long with a diameter of 2m). A perforated pipe was placed in the bags for diffusing air in the piles. Air valves (6-8 per windrow) were used to control the release of exhaust gases. To improve ventilation, the static piles were mixed with wood chips with a ratio 3:1. The optimal ratio was defined taking into consideration the porosity and the C/N value. The composting treatment process was completed in 13 weeks and consisted of 3 phases (Figure 3).

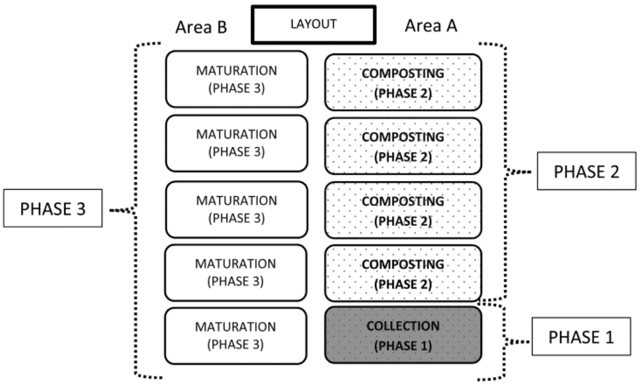

Figure 3. Optimal layout for composting units using static piles (10-stations).

In Figure 3 the suggested layout is displayed and all phases (COLLECTION/ Phase 1, COMPOSTING/ Phase 2 and MATURATION/Phase 3) are presented (Area A for Phases 1&2 and Area B for Phase 3). Composting process is a sequence of the biodegradables' accumulation (week 1), encapsulation and treatment in closed aerated windrows (for 4 weeks), and maturation (for 8 weeks) in open windrows. This is a 10-stations scheme which allows precise monitoring of the success of the phases as well as the optimisation of required resources (space and aeration).

During the initialisation (Phase 1), the biodegradable waste sorted within one week are collected (station 1) and mixed with wood chips and garden wastes (when available). The material is placed in a plastic bag (closed static aerated windrow) for the initialisation of the second phase (Phase 2). Each closed windrow is aerated for 4 weeks. After Phase 2 (week 5), the closed windrows (plastic bag) are opened, and the material is moved to Area B (see Figure 3) for maturation and stabilization for a period of 8 weeks (phase 3). Since there is significant volume reduction during the active phase (phase 2), the material used to form the windrow in phase 3, usually consists of the material coming from two windrows from phase 2 (W_1 & W_2: $Windrow_1$ & $Windrow_2$).

In Phase 3, the material is turned once a week (dynamic aeration) and after 13 weeks the mature material - the produced compost - is assessed with respect to its stability (Scaglia *et al.*, 2000; Iannotti *et al.*, 1994; Oviedo-Ocaña *et al.*, 2015) and refined.

2.3. Determination of parameters affecting the composting process

For closed composting systems, like the one presented here, temperature should exceed 60 °C (JMD 56366/4351/2014) at least for one week to eliminate the pathogens, parasites and weed seeds (Awasthi, 2017; Onwosi, 2017).

In the case of Kalamata, the temperature was measured in 3 different points along each windrow using a field thermometer (OT-21 oxygen/temperature, Demista Instruments, Illinois, USA). In each point, temperature was measured in two depths, 30 cm, and 1 m. The required temperature profile was met by careful monitoring as well as an optimal aeration pattern in Phase 2 (using blowers). Temperature in the current research was monitored every two days during Phase 2 and once a week during Phase 3.

The oxygen content of the air in the pores of the windrows was monitored to evaluate and optimize the aeration profile along with temperature values and was measured using an oximeter (OT-21 oxygen/temperature, Demista Instruments, Illinois, USA).

2.4. Determination of the physicochemical characteristics of the final product

The monitoring program started in November 2013 and run till Spring 2016 and it was organized in 2 sessions (Table 3) due to a change in the Greek legislation. 41 windrows in total were created (6 are presented here; Tables 3 and 4). However, as this was an operational unit, all the produced material was evaluated; the number of samples is defined by the legislation, and it is related to treated volumes in the composting facility.

The produced compost was evaluated with respect to the relevant legislation in both cases.

Compost samples were collected according to EN 12579:2013 «Soil improvers and growing media – Sampling». The mature material was analysed for heavy metals and moisture, parameters set by both JMDs, plastic content, glass content and material granulometry as described in JMD 114218/1997, salmonella and impurities with respect to the JMD 56366/4351/2014.

Furthermore, parameters such as pH, electric conductivity (EC), organic matter (OM), total nitrogen (measured with Kjeldahl method (TKN), C/N ratio, and phytotoxicity have been investigated for the evaluation of the procedure.

Table 3. Monitoring periods and compost sampling

Samples	Monitoring period	Monitoring sessions before and after the change in Greek legislation
Compost 1 (C1)	25/11/2013 - 26/02/2014	2/2014-1/2015
Compost 2 (C2)	15/04/2014 - 19/09/2014	
Compost 3 (C3)	23/04/2014 - 08/01/2015	
Compost 4 (C4)	17/12/2014 - 04/06/2015	4/2015-4/2016
Compost 5 (C5)	26/04/2015 - 25/08/2015	
Compost 6 (C6)	25/08/2015 - 26/04/2016	

Table 4. Qualitative parameters and maximum values according to Greek legislation

Parameter	Maximum value	
	JMD 56366/4351/2014	**JMD 114218/1997**
Cd (mg kg^{-1})	3	10
Cu (mg kg^{-1})	400	500
Ni (mg kg^{-1})	100	200
Pb (mg kg^{-1})	300	500
Cr (mg kg^{-1})	250	510
Zn (mg kg^{-1})	1200	2000
As (mg kg^{-1})	10	15
Hg (mg kg^{-1})	2,5	5
Moisture	<40%	≤40%
pH	-	6-8
PCBs (mg kg^{-1})	≤0,4 on dry matter weight	-
PAHs (mg kg^{-1})	≤3 on dry matter weight	-
Enterobacteria	-	Absence
Salmonella spp.	Absence	-
Impurities > 2 mm	≤3% on dry matter weight	-
Plastic content	-	≤0,3% on dry matter weight
Glass content	-	≤0,5% on dry matter weight
Material granulometry	-	≤10 mm (90 %)
Content of viable weeds and plant propagules	Propagules 3 viable weed seeds per liter of product	-

The organic matter (OM) content was quantified by calculating the weight loss after ignition of a dry sample in a furnace at 550 °C for 8 h (EN 13039:2000). C/N ratio was calculated by the determination of total Kjeldahl nitrogen (TKN) content of solids samples using the modified Kjeldahl digestion method (EN 13654-1:2001) and by the determination of TOC using dichromate method. The determination of pH values was performed using electrometric determination in aqueous extracts (1:10, w/v) of the samples (EN 13037:2011). The content in Zn, Cu, Ni, Cd, Cr, As and Pb was determined using graphite furnace atomic absorption spectrophotometry (Perkin–Elmer Atomic Absorption Spectrophotometer) after digestion of the samples in Teflon tubes at microwave furnace (MARS EXPRESS) followed by filtration (EN 13650, 2001). The determination of Hg follows ISO 16772. *Salmonella* spp is measured according to ISO 6579:2002. Plastic and glass content were estimated using hand and material granulometry by weighting the fraction which passes through a 10mm sieve.

The seed germination technique was used for the determination of the phytotoxicity of compost extracts (Zucconi *et al.*, 1981). 10 ml of water compost extract was applied to filter paper in a Petri dish and 20 seeds (*Lepidum sativum*) were then placed on the filter paper. All the experiments were performed in triplicate. The Petri dishes were sealed with tape to minimize water loss while allowing air penetration and then they were incubated in dark for 72 hours at room temperature. Seed germination percentage and root length of the plants in the extracts were determined. The seed germination in distilled water was used as a control. The percentage of seed germination, root elongation and germination index (GI) were calculated according to the following equations (Zucconi *et al.*, 1981):

$$\text{Seed germination (\%)} = \frac{\text{No of seeds germinated in compost extracts}}{\text{No of seeds germinated in water control}} \text{x } 100\% \quad (1)$$

$$\text{Root elongation (\%)} = \frac{\text{Mean root length in compost extracts}}{\text{Mean root length in water control}} \text{x } 100\% \quad (2)$$

$$\text{Germination index (\%)} = \frac{\text{Seed germination (\%)} \times \text{Root elongation(\%)}}{100} \quad (3)$$

3. Results and discussion

3.1. Determination of the quantities of the recovered materials

The quantities of the recovered packaging materials at the MBT are compared to the blue bin content (recyclable stream) and the results are presented in Table 5. There are significant quantities of iron, aluminum and plastic that are thrown in the mixed stream (green bins). Specifically, for plastics, iron and aluminium, the contribution of the quantities recovered in the green bins with respect to the total recovered materials (green and blue bins) reaches 60% for plastics, 53% for iron and 65% for aluminum. The findings suggest that to meet the targets for recycling and maximize diversion from landfills it is essential to upgrade the recycling programme of packaging material and at the same time to retrieve recyclable materials from the green bins.

Table 5. Quantities of recovered materials from blue and green bin in Kalamata Municipality as measured in 2013-2014

Material	Blue bin (kg)	Green Bin (kg)	Total (kg)	Contribution of the Green bin %
Paper / cardboard	2424		2424	
Tetrapac	40		40	
Iron	110	125	235	53.19%
mixed plastics	531	810	1341	60.40%
Glass	103		103	
Aluminum	22	41	63	65.08%
Recyclables - non packaging (film)	93	9	102	8.82%
Printed paper	761		761	
Total recyclables	4084	985	5069	19.43%
Residue	2138	9280	11418	
Organic		18735	18735	
Total	6222	29000	35222	

3.2. Monitoring of the temperature and oxygen content during the composting process

The optimum temperature for composting biodegradables is ranging from 35 to 70 °C according to literature (Gea *et al.*, 2007; Haug, 1993; Bach *et al.*, 1987; Kuter *et al.*, 1985; MacGregor *et al.*, 1981; Liang *et al.*, 2003). It should not exceed 65 °C, to avoid the reduction of the number of microorganisms and the reduction of the biological decomposition rate. It plays a critical role to the sanitation of the produced compost, therefore constant monitoring is required to control the temperature profile (Golueke, 1977; Hassen et al, 2001; Barrena *et al.*, 2006).

Figure 4. Monitoring of temperature in 6 closed windrows used for composting of OFMSW in Kalamata, Greece.

Several studies present that the auto-sterilization of a windrow is achieved at temperatures below 55 °C (Kuter *et al.*, 1985; MacGregor *et al.*, 1981; Liang *et al.*, 2003). According to the research by Bustamante *et al.* (2008), the occurrence of relatively high thermal values during the composting process does not always ensure a complete sanitation of the compost. In a study conducted by Chroni *et al.* (2009), *E. coli* was not detectable after about 10 weeks of processing and Hassen *et al.* (2001), found that Salmonella completely disappeared when temperature reached 60 °C. Summarizing the literature, a suitable range of temperature for degradation is between 40 and 55 °C and if in a pile it can be maintained from 55 to 70 °C for a few days (more than 3), compost can be sterilized.

As presented in Tables 3 and 6 windrows were fully monitored, and their temperature profiles are presented in Figure 4. A diverse performance is presented that can be accounted to several factors. A critical factor is that the biodegradable material does not has uniform quality as it comes from an MBT and is not source separated. Another factor is the variability of the weather and low air temperature especially during autumn and winter - the cases D and E. Last, the fact that those are close static windrows where the material is not mixed for 5 weeks does not allow for mixing and therefore there are parts with very limited or even no oxygen at all. Most of these problems have been resolved as a mixing of windrows is proposed.

As it has been described in section 2.2., after the completion of phase 2, part of the material from the pairs of closed windrows is used to form an Open Windrow ($W_{1,2}$) to complete maturation (phase 3). The temperature profile of entire composting process (phases 2 & 3) for a combined pair of Windrows is presented in Figure 5.

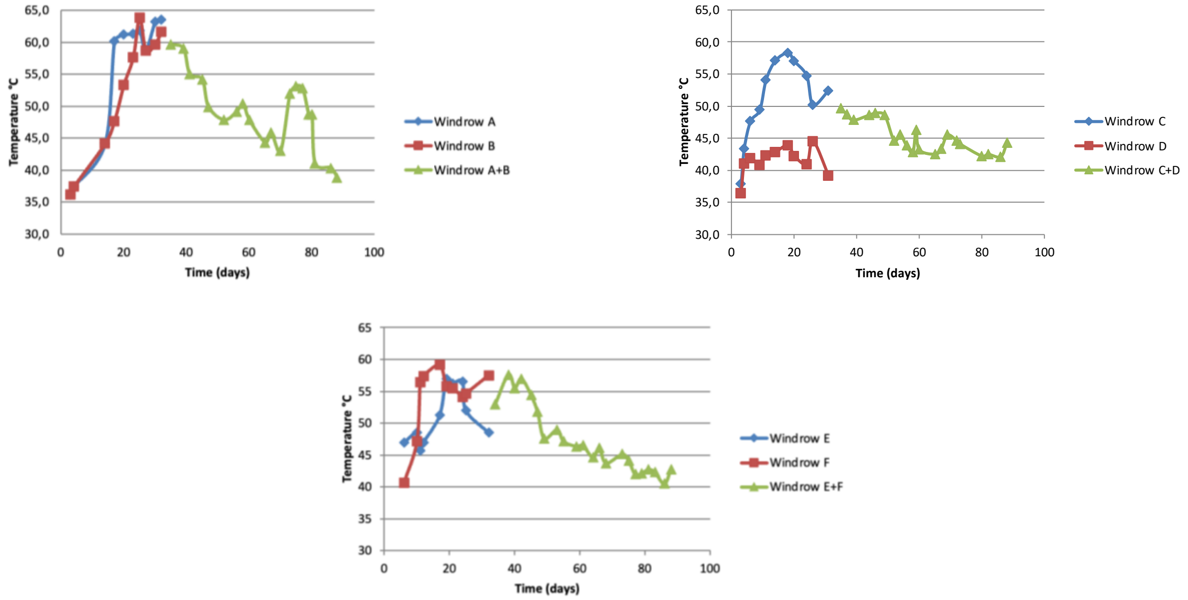

Figure 5. Monitoring of temperature in pairs of closed windrows before (phase 2) and after the formation of the combined open windrows in phase 3 ($W_{A,B}$, $W_{C,D}$, $W_{E,F}$)

In Figure 5, it can be seen that there are differences in the performance between the closed windrows used to form a pair (during phase 2). These differences may be related to the heterogeneity of the input materials. In most cases, temperature values were found to be in the suggested range, while mixing results in better homogeneity and a typical behavior. Especially in the case of the pair shown in Figure 5, the temperature of the material in Windrow D increases only after the mixing and the formation of the Open Windrow (W_{C+D}). As a result, mixing in the maturation phase (phase 3) can be considered as a corrective action in order to support the sanitation process in cases of diversion from the optimal profile.

The moisture content is very critical for the composting process as it provides the aquatic media required for the nutrients to be transferred to microorganisms. It should be high enough to support biological activity, but not too high as to avoid filling the space (pores) that can provide the required oxygen for aerobic microorganisms. The optimum range for MSW biodegradables varies between 45 and 60% (Tchobanoglous *et al.*, 1993; Hachicha *et al.*, 1992).

Apart from temperature, oxygen content is a critical parameter for supporting the biological activity. The optimum level of oxygen ranges between 5 and 20 (%, v/v) (Haug, 1993). In the current study, closed windrows were aerated by electric blowers that pushed air through the compost at different aeration rates of 40-80 L/min and intervals: from 15-30 minutes every 2-3 hours.

With optimal aeration handling, the oxygen content was kept between 15-20%, however the temperature values did not follow a typical profile and exhibited a delay during the first 10 days, since continuous aeration cooled the windrow and restrained the heating-up of the piles. This finding agrees with results from the literature, stating that oxygen levels under 5% can cause anaerobic conditions, whereas levels over 15% are indicative of excessive aeration which tends to cool the material (Leton & Stentiford, 1990).

3.3. Determination of the physicochemical characteristics of the final product

Heavy metals were detected in all the samples analyzed, with concentration levels lower than the limits set by national legislation. The presence of heavy metals in the final product could be attributed to the composition of the initial mixture. Municipal solid waste may contain household dust, batteries, electric devices, paints, inks, personal care products, medicines and household pesticides (Bardos, 2004). The concentration levels below the limits, are related to recycling schemes and the separate collection of electric devices, batteries, lamps etc which are operated in Kalamata municipality. The concentration of heavy metals increases during the composting process due to the microbial degradation of a part of the organic matter and the loss of volatile solids (Garcia *et al.*, 1995; Ciavatta *et al.*, 1993; Das *et al.*, 2002). The aerobic composting can immobilize the exchangeable pool of heavy metals in the organic wastes (Paré et al, 1999). The compost derived from source-segregated waste streams or garden wastes is generally reported to contain smaller amounts of heavy metals compared to mechanically sorted products (Epstein et al, 1992; Sharma *et al.*, 1997). Even though the OFMSW in this study was diverted mechanically, all the values of the physicochemical parameters were below the limits set by the legislation. All the results are presented in Table 6.

Although the concentration levels of heavy metals are not exceeding the maximum values, the compost cannot be considered suitable for agricultural purposes or for gardening, since it is produced from material diverted from an MBT. This result is consistent with previous findings on the qualitative characterization of compost from MSW. The maximum values set by the legislation in the Member states are similar (Montejo *et al.*, 2015).

The moisture content values were found to be within the legislation limits. In two samples (C3 and C6), the values exceeded the limits, but that could be related to rainfall events as the produced compost was not covered.

None of the composts samples has been found positive for *Salmonella* spp presence. *Salmonella* spp is eliminated in thermophilic phase when temperature is maintained at 55 °C for a few days as reported in the previous section.

The composting process has been evaluated using some other parameters as well, such as pH, EC, ash content (which represents the organic matter that did not degraded), nitrogen content, ratio C/N and phytotoxicity. These are considered as critical parameters for the characterization of the compost quality as crop substrate, but because of the legislation prohibition they are determined as factors of the process along with organic matter content and C/N ratio.

Table 6. Determination of physicochemical parameters in compost samples; final product evaluated according to legislation at the time of sampling

Parameter	JMD 1997				JMD 2014			
	C1	C2	C3	Limit	C4	C5	C6	Limit
Cd (mg kg^{-1})	0,47	0,37	1,55	10	3,78	1,73	1,85	3
Cu (mg kg^{-1})	189	93,7	215	500	216	260	95	400
Ni (mg kg^{-1})	77,1	28,0	53,5	200	42,4	43,8	45,7	100
Pb (mg kg^{-1})	204	56,2	129	500	146	127	168	300
Cr (mg kg^{-1})	43,9	26,1	31,9	510	155	39,3	42,3	250
Zn (mg kg^{-1})	114	154	542	2.000	478	484	397	1.200
As (mg kg^{-1})	1,95	4,21	3,92	15	0,10	4,95	4,01	10
Hg (mg kg^{-1})	2,18	3,18	2,54	5	0,89	2,38	1,95	2,5
Moisture %	39,3	32,3	40,9	≤40%	33,2	31,5	56,4	<40%
pH	8,82	8,91	7,15	6-8	7,91	8,49	8,51	-
Salmonella spp.	-	-	-	-	absence	absence	absence	absence
Impurities > 2 mm %	-	-	-	-	15,3%	10,2%	11,8%	≤3% on dry matter weight
Plastic content %	4,76	4,87	3,13	≤ 0,3% on dry matter weight	-	-	-	-
Glass content %	3,56	6,34	6,76	≤ 0,5% on dry matter weight	-	-	-	-
Material granulometry %	56,3	67,2	62,5	≤10 mm (90 %)	-	-	-	-
OM %	42,9	44,0	43,1	-	48,2	44,3	40,7	-
TKN %	1,18	1,32	1,81	-	1,63	1,40	1,81	-
C/N	20,2	18,2	13,2	-	16,4	17,6	12,5	-
GI (%)	66,50	66,50	77,40	-	79,20	69,60	80,60	-

In most of the compost samples, the organic matter was found to be below 60%, even below 45% in some cases. The only parameter whose values are exceeding the legislation limits are the impurities and this is related to the equipment used for the final refinement (20mm sieve). Smaller hole size could achieve better results.

Furthermore, there are two significant parameters that are recognized by the studies in composting in order to evaluate the process and these are stability and maturity. It is not sufficient to examine only one of them, so both should be determined (Komilis, 2015). Compost stability is related to microbial activity in the compost (Iannotti *et al.*, 1994), while maturity is connected to the absence of phytotoxicity (Wu *et al.*, 2000).

The germination index (GI) results have showed that none of the tested compost is phytotoxic and this explained that the GI is over 60% the threshold limit of 60% stated by Zucconi and de Bertoldi (1987).

4. Conclusions

This paper presents a methodology for the management of MSW with a mobile MBT unit. Effort has been placed to improve the performance of all the subunits and particularly the composting unit that treats the OFMSW which accounts for 40% of the MSW in Kalamata. An important aspect that needs to be taken into consideration is the fact that the case study and the results presented here are from a large-scale application in an operational mobile unit treating more than 30000 tons of MSW per year. The use of mobile equipment, because of sudden changes in waste management practice in the region, introduced several problems and limitations. The proposed scheme with closed and open windrows as well as the combination of the material from two separate windrows during phase 3, supported the composting processes with minimum infrastructure and space.

The detailed monitoring of critical parameters and the analytical measurements of temperature and oxygen content allowed the evaluation of the performance of several trials as well as the optimization of aeration patterns, mixing of materials (including the bulking agents).

The final composted material was analyzed, and the values of the parameters were found to be within the legislation limits. However, according to Greek JMD 56366/4351/2014, the product of the composting process of OFMSW diverted in an MBT cannot be used in agriculture or gardening. During the period of this study, Kalamata municipality diverted the 67% of its MSW (combined performance of MRF & MBT) from landfill and has treated significant quantities of OFMSW that were used for the remediation of the closed dumpsite.

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