



Performance of a new household composter during in-home testing

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ABSTRACT

This article presents the methodology and the results of the performance testing of a prototype system for the production of high quality compost from biodegradable household waste separated at the source. Selected households in three municipalities of the Attica Region in Greece constituted the users of the home composter. The results indicated the effective operational performance of the prototype household composter in practice (use of the system by the householders on a daily basis), as well as the high level of response of the householders in adopting the composting practice in their daily activities as common practice. The compost that was produced in the households was characterized by high quality, which is in accordance with the quality standards that are set for its use. In only a few cases (in the first cycle of the pilot implementation) the quality of the compost was not high due to the fact that some householders were not yet familiar with the use of the composter, but these operational problems were solved and the compost that was later produced was considered high quality.

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1. Introduction

Biodegradable organics comprise the major waste fraction generated by households worldwide. They consist primarily of kitchen waste, and can comprise up to 50% (w/w) of total household waste (EEA and ETC-WMF, 2002). In order to ensure the proper management of this waste stream, it is necessary to implement efficient practices and schemes that promote sustainability and are based on the provisions and the principles of environmental policy and legislation (EC, 1999 and EC, 2006).

In the Attica Region of Greece, the most densely inhabited area of the country (with a population of 4 million people, corresponding to about 40% of the total population of the country), is comprised of 92 municipalities and 30 communities. According to analytical primary data that was collected and assessed, the quantity of mixed household waste generated annually in the Region is 2,681,999 tons, out of which: 2,518,094 tons (93.89%) are transferred to the central sanitary landfill in Athens, 51,154 tons (1.91%) are transferred to other smaller sanitary landfills and 112,753 tons (4.2%) are disposed at semi-controlled landfills. Some programs are in place for the recovery and recycling of materials from municipal waste (glass, paper, plastics, metals) in the Attica Region. These materials are transferred to two recovery centers where they are separated into categories and sent to end users in Greece or abroad (NTUA, 2006).

One promising option for the management of domestic organic kitchen waste (DOKW) is to encourage the householders to separate and compost the waste at home. For this purpose, a prototype system for the simultaneous separation and composting of household organic waste at the source was designed, constructed and then evaluated through its pilot application at selected households in three municipalities of the Attica Region in Greece. The aim was to test and evaluate the operational performance of the prototype household composter under actual conditions (use of the system by the householders on a daily basis), as well as to define the level of response of the householders to adopting the composting practice in their daily activities as common practice.

2. Methodology

2.1. Selection of households for trial use

The pilot application of the system was implemented at the Municipalities of Kifissia, Nea Halkidona and Acharnes. The qualitative and quantitative characteristics of the waste generated in the households of the three municipalities were recorded and analyzed in order to identify the quantity of biodegradable organic waste that was used for household composting and, also, to estimate its potential level of diversion from the mixed waste generated at the households.

Table 1 presents data related to the quantities of the generated household waste in the three municipalities – participants in the pilot program. The table shows that the quantity of household waste that is generated per inhabitant daily is consistently higher

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Table 1
Data related to the production of household waste in the three municipalities

Municipality	Population	Annual quantity (tons)	Quantity (kg)/inhabitant day
Acharnes	75,341	58,400	2.12
Kifissia	43,929	33,125	2.07
Nea Halkidona	10,112	10,950	2.97

than 2 kg. Also, it must be noted that all of the household waste generated in the Municipalities of Acharnes and Nea Halkidona is transferred to the central sanitary landfill of the Attica Region for final disposal. In the Municipality of Kifissia, a small amount of recyclable materials is recovered through recycling programs (about 4380 tons annually), while the remaining amount (28,745 tons/yr) is disposed at the central sanitary landfill.

Additionally, Table 2 presents the results concerning the qualitative characteristics of the household waste generated in the three municipalities. The average values of the household waste (HW) contents were obtained by analyzing primary data maintained by the Association of Communities and Municipalities of the Attica Region, Greece which is responsible for the management of the municipal waste in the area where the three municipalities are located. The kitchen biodegradable organics fraction, which is the waste sub-stream/substrate for household composting, constitutes the main fraction of the domestic waste generated in the three municipalities, exceeding 45% (w/w).

The specific characteristics of the households in the three municipalities were identified, recorded and assessed through visits to households, interviews with the householders and filling in questionnaires that were prepared specifically for this purpose. The residents were willing to collaborate with the working group and, therefore, it is believed that they provided correct and representative information. The outcome of this activity was to obtain a clear and integrated picture of the existing conditions that prevail in the households under study so as to select the households that would participate in the pilot programme in a way that would be representative of all households located in each municipality. In particular, about 500 questionnaires were filled out by households, and a majority of them (more than 400 householders) expressed their willing to participate in the pilot household composting application.

The questionnaire that was used for the identification of the characteristics of the households included 29 individual questions, out of which: four refer to general information (number of persons per household, age, educational level and occupation of each householder), three to the standard of living (employment of a household assistant, annual income, number and type of vehicles owned by the inhabitants), three to information on the house building (block of flats – apartment building or detached house, existence of garden or courtyard, surface of the entire house and its kitchen specifically), seven to food routine/habits (how many

Table 2
Characteristics of the household waste generated in the three municipalities

Content (% w/w)	Acharnes	Kifissia	Nea Halkidona	Average
Biodegradable organics	48.38	45.52	46.91	46.94
Paper-cardboard	22.29	25.12	23.20	23.54
Textiles, wood, rubber, leather	4.33	3.79	4.11	4.08
Plastic	9.68	11.61	11.07	10.79
Metals	4.15	4.46	4.59	4.40
Glass	3.67	3.78	3.42	3.61
Inerts	3.23	2.76	2.96	2.98
Other (mixed materials)	4.27	2.96	3.74	3.66
Total	100	100	100	100

times each inhabitant has a meal in the residence daily, how many times they cook daily, for how many people the meal is prepared, what the food includes generally, quantities of fruits and vegetables that are consumed, whether the residents prefer fresh or frozen vegetables, frequency of buying and use of standardized food products), two to time spent at home by the inhabitants (how many hours each inhabitant stays at home, daily and how many times each resident is absent from the house for time interval more than 1 day, monthly), seven to the level of environmental conscience (level of environmental conscience of residents, as it is determined by themselves, whether they buy products that are environmental friendly, whether they have ever participated in environmental programs, whether they consider that such programs are needed in their municipality, whether they would participate in such programs and whether they are informed about the collection and utilization of waste at the source) and, finally, two questions refer to the way to be informed on environmental programs (whether the householders have access to internet and ways through which the residents wish to be informed on the environmental activities that are developed at their municipality). By assessing the content of the questionnaires, 30 representative households from each of the three municipalities were selected (90 in total).

2.2. Prototype household composting system

An extensive analysis of 33 household composting systems that are available in the market was carried out. In particular, 19 static home composters, seven rotating or overturn home composters, three home composters with mechanical mixing system and four composite home composters were examined. The evaluation of the systems was carried out via the development and application of a multi-criteria method of analysis, which is based on a wide range of criteria that are numerically weighed (factors of gravity) according to their importance (degree of importance). These criteria are divided into three main categories (groups of criteria) that also are numerically weighed: technological (17 criteria), environmental (seven criteria) and economic (eight criteria). Through the analysis of the results that were obtained from the comparative evaluation via the multi-criteria method, conclusions on the operational performance as well as to the most effective features of the available systems were made.

Taking these conclusions into consideration, the first version of the prototype system components was manufactured and tested. After the completion of the lab testing of the individual components of the prototype system, the first pieces of the entire system were manufactured and their functions were re-examined in order to ensure that the required performance had been achieved. By completing this re-examination, the technical characteristics of the entire system were finalized and 90 pieces of the prototype system were produced and installed at the 90 selected households.

The prototype system (Fig. 1) is based on mechanical mixing, aerobic degradation and stabilization of DOKW on continuous basis. Its inner volume is about 126 l, while its total volume is about 128 l (height: 65 cm and diameter: 50 cm). It consists of four individual and segregated compartments, as follows:

- Feeding
- Composting process
- Compost collection and removal
- Leachate collection and removal

The capacity of the feeding semi-cylindrical compartment is 9.6 l (Fig. 2a). The feeding of the organic kitchen waste is achieved through the manual movement of its rotating cap. After inserting the organic waste into the feeding compartment, the rotating cap



Fig. 1. The prototype household composting system.

is closed manually, isolating the content from the external environment. The capacity of the feeding compartment is adequate for the storage and mixing of the generated organics. The average daily quantity of DOKW generated by a typical household is estimated

to be 2 kg or 1.6 l. In order to achieve optimum system operation, it is suggested that the feeding compartment should be emptied every 2 days. The transfer of the organics from the feeding to the composting compartment is accomplished via manual rotation of

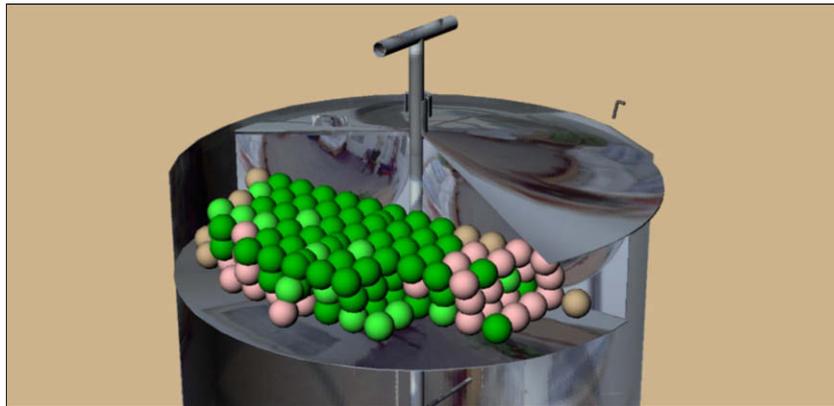


Fig. 2a. Feeding compartment.



Fig. 2b. The transfer of organics from the feeding to the composting compartment.

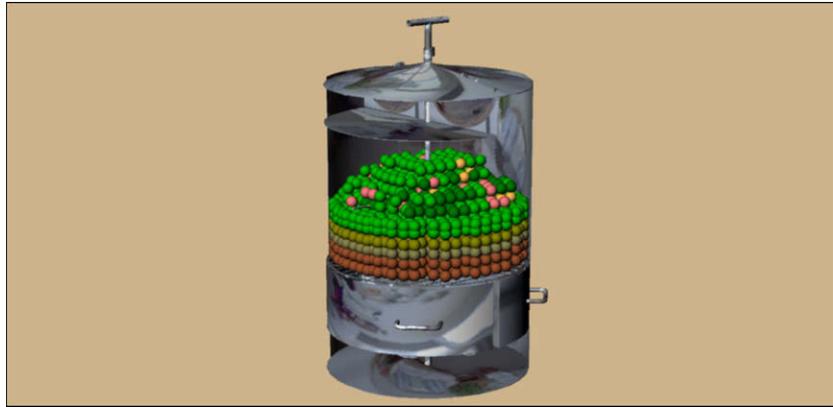


Fig. 2c. The composting process compartment.

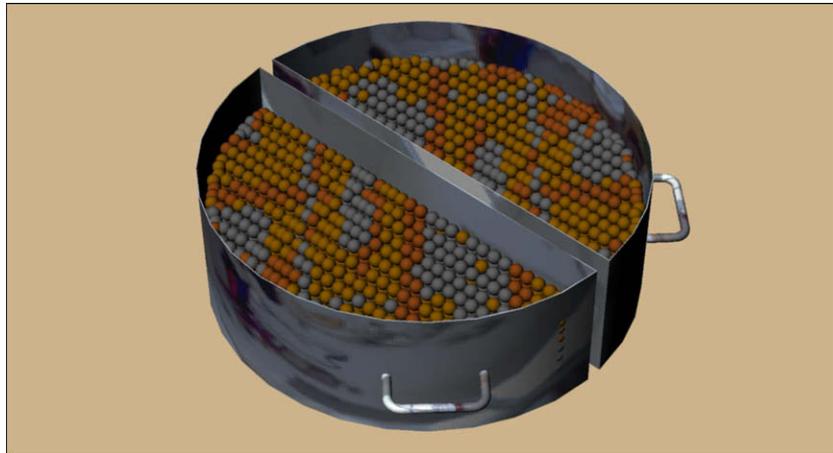


Fig. 2d. Compartment for the collection and removal of compost.

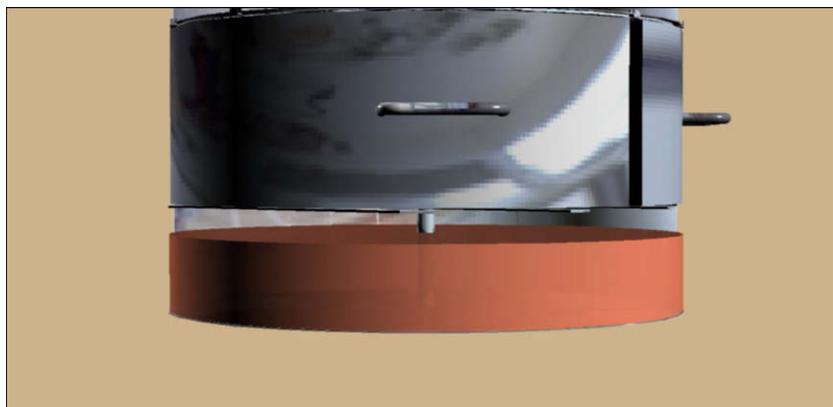


Fig. 2e. Compartment for the collection and removal of leachate.

the diaphragms of the mixing/stirring shaft (rotation up to 180°) (Fig. 2b). These functions allow the insertion of new material in the feeding compartment without contact with the composting compartment and its content and, additionally, the transfer of the raw organic material to the composting material is achieved without opening the cover of the feeding system.

2.2.1. Composting process compartment

The capacity of the composting cylindrical compartment is 66 l. It receives organics when the shaft is turned and material is present in the feed compartment. The pile of the organics in the compartment is comprised of layers of organics with different levels of degradation, as presented in Fig. 2c (the lower layers are related to

degraded or/and partially degraded organics, while the upper ones include the new input of organics).

According to the system design, the organic material is stirred when new material is introduced from the feeding to the composting compartment. At this time, air enters the composting compartment when the shaft is turned and is interfused into the substrate in the composting compartment by manual stirring. Favorable temperature conditions (mesophilic and thermophilic composting phases) are developed when the volume of the organic material in the composting compartment is about 20 l (a volume of organics that is generated by a typical household within 2 weeks) and the residence time of the organics in the composting compartment is about 5 weeks. The moisture content of the organics that are subjected to composting is sustained between 55% and 60% (w/w) of fresh material, level that is favorable for the process development. Also, small quantities of additives are introduced to the organic substrate (natural zeolite, mature compost and sawdust) to improve the composting process. Analytical information related to the additives is given in Section 2.4.

During the rotational movement of the stirrer, new fresh material enters into the core of the process, while the lower shaft mixes the composted organic particles upwards of the separation grate. During mixing, the composted organic particles pass through the grate grid and they accumulate in two compost receptors (Fig. 2d). Each of the two semi-cylindrical receptors has a capacity of 14.7 l (total volume of collected compost up to 29.4 l). The receptors can store compost for a time period up to 65 days (quantity of compost that is produced after two composting cycles). Nevertheless, it is suggested that it is emptied every month. The compost receptors are detached manually using the specific hatches of the cylindrical jacket and the compost is removed.

The compartment for the collection of the generated leachate is the lowest part of the system; its capacity is 19.3 l (Fig. 2e). The leachate from the composting compartment enter into the leachate compartment via gravity, initially through the grate to the compost compartment and, then, through vents that are incorporated into the compost compartment.

The inner layer of the composting system is constructed with stainless steel. The outer layer is constructed with commercial heat insulation sheeting with very low thermal conductivity, in order to avoid the loss of heat from the composting compartment. This insulation material restrains the biochemically produced heat due to its closed cell structure (density: 50 kg/m³, thermal conductivity: ≤ 0.042 w/m K).

The prototype system has significant comparative advantages, compared to other available household composting systems, since it has the following unique characteristics:

- *Separate feeding system:* Minimization of odours from the composting compartment during feeding of fresh organic material, simplified and fluent feeding procedure.
- *Composting compartment (reactor vessel) that is isolated from the feeding system:* Avoids the mixing of fresh organic material with the composted material, the procedures for adding fresh organic material and the collection of composted material do not affect the composting procedures.
- Collection of leachate.
- Agitation system avoiding the contact of waste with the finished compost.
- Use of specific additives and in particular: (i) clinoptilolite, a natural zeolite of Greek origin, assisting in the control of odours and quality improvement of the composted product; (ii) mature compost and sawdust for acceleration and improvement of the process development.

- The composting system operates on continuous basis (continuous feeding of new organics in parallel with continuous removal of the composting product).

2.3. Training of the householders

Specially organized training modules took place in order to explain the use of the prototype composter in detail, to the participating householders. During these training sessions, practical demonstration of the use of the system was given and, also, information and training material was distributed to the participants. Additional training was provided to the people that participated in the programme during the installation of the system at each household. Moreover, during these training activities, the householders were informed on how to identify the compostable waste (a list of potential compostable kitchen residues was given to them) and how to separate them from the mixed kitchen waste.

2.4. Implementation of the pilot household composting programme

As mentioned previously, 90 prototype composting systems were installed at selected households (30 households at each of the three municipalities). The householders were provided with the prototype system, as well as with additives that were used for the efficient process development. In particular, the householders fed the system with the appropriate biodegradable waste generated in their kitchen together with Greek natural zeolite (clinoptilolite) of a specific proportion, 2–5 mm (5%, w/w), in order to eliminate the odor and improve the quality characteristics of the final product. This size range was found to be the most effective for its use in the composting process, according to the experimental results that were obtained from previous laboratory work (Zorpas et al., 2002). Moreover, a low quantity of mature compost (5%, w/w) was added to the organic substrate to support the startup of the composting process, as well as a specified quantity of sawdust (5%, w/w) to improve the quality characteristics of the household waste (increase of the carbon content that was available for the development of the biochemical actions in the composting compartment by the microorganisms and optimization of the aeration conditions and the moisture content of the material that was subjected to composting).

Determination of the quantities of additives used by the householders was carried out by developing experimental laboratory trials. In particular, nine experimental series were developed using different combinations of quantities of additives (dosages) in each of them. The obtained product was temporarily stored by the householders in appropriate biodegradable bags for further maturation and stabilization (the temporary storage lasted for 1 month). The bags have a capacity of 20 l (corresponding to 12–14 kg of compost). A typical household produces 175 kg compost on annual basis. As a result, 13–15 bags are required during the entire year (approximately 1 bag per month). Consequently, the space that is needed for this purpose is extremely low.

The household composters were used by the householders for a sufficient time period (each composting cycle lasted about 5 weeks and three complete cycles were completed by each of the participating households). In this way, the householders became familiar with the separation and composting process and adopted it as daily common practice. The research working group was in constant communication with the householders participating in the program (visits at the selected households on weekly basis, frequent phone communication) in order to overcome potential difficulties and malfunctions. In addition, the householders were provided with a telephone number where they could get required information and receive replies to their questions. Further explanations

and directions were given to some householders at the beginning, when the system was installed. Also, in some cases, additional instructions were provided to some householders during the operation of the system in order to improve performance (e.g. elimination of odors). Overall, the implementation of the program ran smoothly and the cooperation of the householders with the members of the research working group was continuous and efficient.

A questionnaire was distributed to the householders that used the prototype home composter, and householders were asked to complete it regularly with their observations and remarks about the system operation. The content of the questionnaire is given in Table 3, synoptically.

The compost that was produced was used by the householders in their gardens and flowerpots as soil improver. Additionally, the collected leachate (2.1–3.2 l per composting cycle) was diluted with water and used by the householders to irrigate flowers, trees, grass and bushy plants.

Additionally, compost samples from all the participating households were collected and analysed at the lab to determine the quantitative and qualitative characteristics of the product and assess its quality. From the 90 composting bins, 270 compost samples were collected and analysed (30 samples per composting cycle \times 3 composting cycles for each of the three municipalities).

2.5. Evaluation of the implementation of the pilot program

The performance of the home composter was evaluated taking into consideration:

- (i) The monitoring questionnaires that were filled in by the participating householders.
- (ii) The quantitative and qualitative characteristics of the compost that was produced using the prototype systems. The parameters that were examined for each sample, using standard methods, were: moisture content, pH, organic content (% Corg), nitrogen content (% N), carbon/nitrogen ratio (C/N) (Tan, 1996; APHA, 1998).

Also, phytotoxicity was assessed through seed germination tests (Fuentes et al., 2004). Compost extracts (three replicates for each type of compost) were prepared by shaking 10 g of compost samples with 100 ml of distilled water. The suspension was then centrifuged and filtered before being introduced into a polyethylene tube and was kept at 4 °C. Lettuce seeds were used for the germination tests. A 10 ml aliquot or extract was added to a petri dish

with Whatman no.1 ashless filter paper; 20 seeds were placed in each dish (three replicates for each sample). The plates were incubated at 25 °C in the dark. Distilled water was used as a control. Seed germination and root length in each plate were measured at 5 days. In both germination tests, the percentages of relative seed germination (RSG), relative root growth (RRG) and germination index (GI) after exposure to compost extracts were calculated as follows:

$$\text{RSG (\%)} = \frac{\text{number of seeds germinated in compost extract}}{\text{number of seeds germinated in control}} \times 100 \quad (1)$$

$$\text{RRG (\%)} = \frac{\text{mean root length in compost extract}}{\text{mean root length in control}} \times 100 \quad (2)$$

$$\text{GI (\%)} = \frac{\text{RSG} \times \text{RRG}}{100} \quad (3)$$

The samples were taken from the mature compost that was stored in the appropriate biodegradable bags kept by the householders and the experiments took place in duplicate (two samples were taken from the same compost and all parameters were determined twice). The results that were presented in the article are the average value of the values that were determined by this duplication of the measurements.

3. Results and discussion

3.1. Problems that arose during the implementation of the pilot program – operational measurements

The main problems encountered during the use of the household composters, as recorded in the monitoring questionnaire completed by householders, were: presence of odour, difficulty of rotation of the shaft, clogging of the leachate collection tap, generation of quite high quantities of leachate, clogging of vents of the internal grate and the presence of insects. These problems were noticed mainly during the first stages of the implementation program (first composting cycle running for 5 weeks) due to the fact that the householders were not fully familiar with the use of the prototype composting system. The direct and on time response of the members of the NTUA working group in combination with the high level of collaboration of the householders led to the quick and efficient elimination of these problems. As a result, further use of the system by the householders took place without problems.

In these cases, measurements were not carried out, since it was obvious that the systems did not operate in an effective way and instructions were given to the householders in order to overcome the identified problems. The results that were obtained by carrying out operational measurements at the households (home composters which operated efficiently and composters for which the operational problems were corrected) were:

- *Moisture of the material:* Moisture plays an important role in home composting, supporting microbe movement, nutrient transport and chemical reactions. Too much moisture leaches out valuable nutrients and block oxygen to the compostable material. Too little moisture dries the material and does not support microbial growth. The moisture content of the organic material during the composting process decreased from 75% to 52%.
- *Temperature in the composting compartment:* During the process development, the temperature increased gradually from 20 to 44 °C, reaching a peak of 56 °C. This is a result of the heat generation from microbial activity. The generated heat was spread by mixing and did not remain localized. The highest temperature

Table 3
Monitoring questionnaire

<i>Macroscopic observations and remarks on the process</i>
Presence of insects
Presence of worms
Odor emissions
Production of compost (quantity, texture, etc.)
Generation of leachate (quantity, presence of odor, etc.)
<i>Technical observations and remarks on the operation of the system</i>
Clogging of the tap at the compartment of leachate collection
Way and convenience of rotating of the shaft of the system
Quantity of material in the composting compartment
Leakages of liquids
Condition of the blades and flaps of the system
<i>Measurements during operation (carried out by the research working group)</i>
Moisture of the material
Temperature in the composting compartment
Ambient temperature
Oxygen content in the composting compartment
Quantity of leachate that has been generated

values were kept for a time period from 5 to 7 days. Then, the temperature was decreased, reaching a value of 28 °C, as microbial activity decreased due to lower level of the available organic matter. Maintaining the elevated temperature for a sufficient time period is essential for destroying the pathogens that may be present in the compostable material.

- **Ambient temperature:** The ambient temperature ranged between 22 and 32 °C – a common temperature range in Greece – and did not affect the development of the process. Moreover, the enclosed design of the complete-mix type composter minimized the potential heat loss from the composting compartment.
- **Oxygen content in the composting compartment:** The oxygen content in the composting compartment ranged from 18.8% to 19.9%, values that are suitable for the development of the process. Through aeration, the oxygen needed for the development of the activity of the microorganisms is provided. Also, oxygen-rich conditions within the core of the compostable material eliminate offensive odors. Finally, aeration expedites the composting process through the mechanism of heating insofar as the elevated heat drives biochemical processes faster.
- **Quantity of leachate that has been generated during operation:** The quantity of leachate generated ranged from 2.1 to 3.2 l per composting cycle.

3.2. Evaluation of the characteristics of the household compost

The produced compost was removed from the household composter after the completion of each composting cycle (5 weeks) and was temporarily stored and mixed periodically in biodegradable bags for a month in order to be completely stabilized. Then, compost samples from all participating households were collected and analysed at the lab in order to determine the quantitative and qualitative product characteristics and assess its quality. The lab results are presented below (A1–A3: composting cycles developed at the Municipality of Kifissia, B1–B3: Municipality of Nea Halkidona and C1–C3: Municipality of Acharnes):

3.2.1. pH

The pH values of the household compost (minimum, maximum and mean values) ranged from 7 to 8.7 (Fig. 3). The majority of the samples have slightly alkaline pH due to the addition of zeolite.

In most national standards that define pH limits (e.g. Italy, Belgium), composts should have a pH value within the range of 6.0–8.5 (Hogg et al., 2002). The EC Decision on awarding the eco-label (EC, 2001a) and the EC Proposal of Biowaste Directive (EC, 2001b)

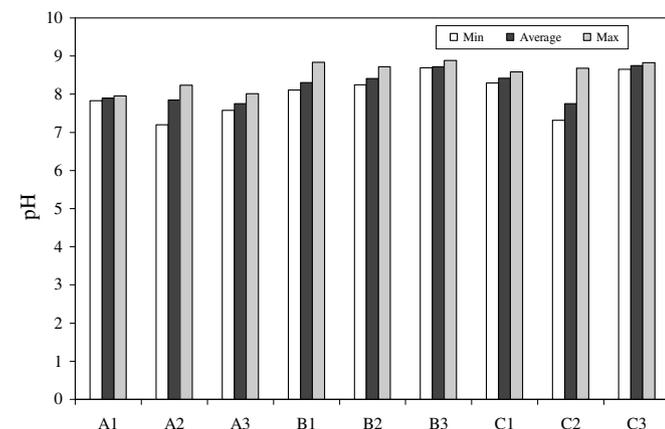


Fig. 3. pH values of household compost samples.

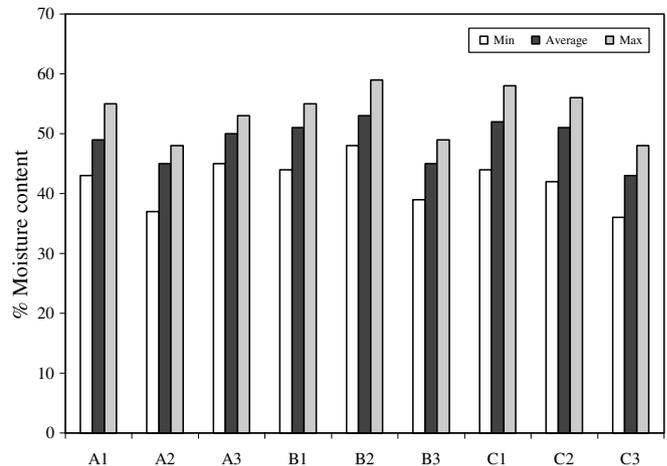


Fig. 4. Moisture content of household compost samples.

require that information to be provided on the product pH but they do not set limits.

3.2.2. Moisture

Fig. 4 presents the results related to the moisture content of the compost samples after their stabilization. The average moisture content ranged from 43% to 53%, values that are considered favorable since the moisture content of mature compost ranges from 35% to 55% (Kapetanios, 1990; EC, 2001a; Hogg et al., 2002).

In general, moisture content varied widely, even among composts of the same group. The most commonly met limit value is 45% (Italy, Luxembourg and Germany) (Hogg et al., 2002), while the minimum requirement of the eco-label standard for soil improvers and growing media is 25% (EC, 2001a).

3.2.3. Carbon

Fig. 5 illustrates the results concerning the concentration of the organic carbon in the mature compost samples. The carbon loss occurred through bio-oxidation of C to CO₂ during composting. The emission of carbon dioxide was significant and reduced the contents of carbon in the compost. The carbon dioxide can escape as a gas or dissolve in the liquid, forming carbonic acid (H₂CO₃), bicarbonate (HCO₃⁻) and carbonate (CO₃²⁻) (Sundberg, 2003).

The average values ranged between 19% and 32% and are compatible with those reported in the literature about mature compost, 18–35.5% (Kapetanios, 1990). The fluctuations that are noted concerning the minimum and maximum values of organic carbon are attributed to the differences in the type of kitchen

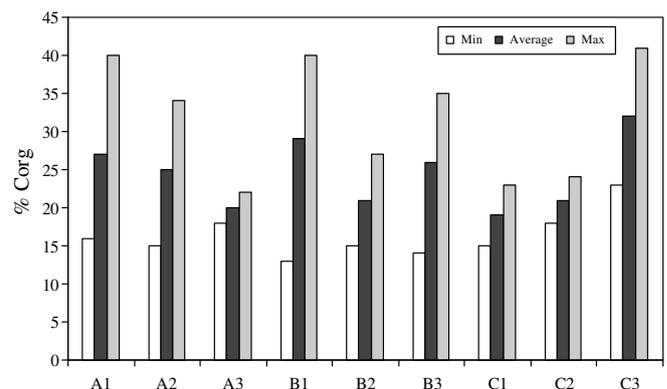


Fig. 5. Organic carbon content of household compost samples.

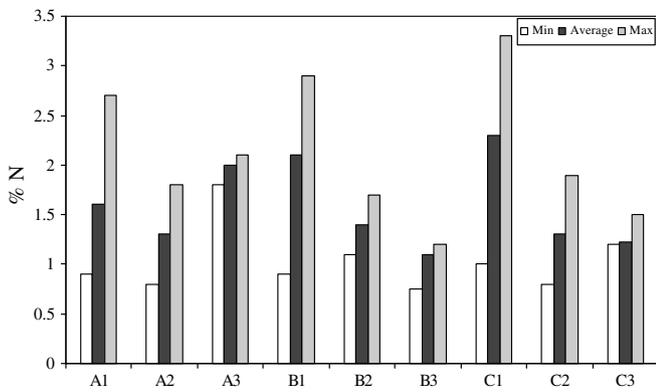


Fig. 6. Nitrogen content of household compost samples.

waste used by the householders as feedstock in the composter (food routines and seasonal variations). Also, according to the EU suggested standards, compost should contain no less than 20% organic matter (EC, 2001a,b), a value that corresponds to organic carbon content higher than 18%.

3.2.4. Nitrogen

Fig. 6 illustrates the results related to the nitrogen content in the compost samples. The average values ranged from 1.1% to 2.3% (minimum value: 0.8%, maximum value: 3.3%). According to reported data, the nitrogen content of compost from household biodegradable waste ranges from 1.1% to 1.9% (WSD, 1994). Also, the standard values suggested by EC indicate that the content of nitrogen should be lower than 2% (EC, 2001a,b). The nitrogen values that exceeded the suggested and reported thresholds were observed during the first cycles of the application in some households, when the householders were not fully familiar with the procedures that should be applied. These values affected the C:N ratios that were determined in the same compost samples (Fig. 7).

The high variability of the nitrogen values of the compost samples can be explained by the fact that nitrogen transformation during composting is affected by a series of parameters.

When more nitrogen is available than what is necessary for microorganisms to use carbon (low C:N ratio), large quantities of ammonia and volatile forms of nitrogen are produced and released. When the required amount of nitrogen-to-carbon for bacterial utilization is present (C:N ratio about 30:1), decomposition proceeds without appreciable loss of nitrogen. Finally, when nitrogen is low in relation to carbon (high C:N ratio), microorganisms use all the

nitrogen for decomposition; some of the microorganisms die and their nitrogen is recycled.

Ammonia releases as ammonia hydroxide as the pH rises above 7. In the later stages of composting the pH may rise to between 8 and 9. At this time there should not be an excessive amount of nitrogen present as ammonia.

The moisture content of compost affects nitrogen conservation less than the C:N ratio and the pH. Ammonia release is higher when the moisture content is low, since the water serves as a solvent and diluent for the ammonia, thereby reducing vapor pressure and volatilization. A moisture content ranges from 40% to 60%, and assists in conserving nitrogen.

Aeration and turning affect nitrogen conservation. If ammonia is present, it escapes more easily when material is disturbed and exposed to the atmosphere. However, if the initial C:N ratio is high enough, nitrogen losses during turning are low.

High temperatures increase volatilization and escape of ammonia. Since high temperatures are fundamental in aerobic composting and destruction of pathogens, not much can be done about controlling temperatures other than to avoid temperatures above 70 °C which retard bacterial activity and permit ammonia accumulation. The highest ammonia loss occurs during the early stages of active decomposition.

Finally, the nitrogen initially present in the compostable material may affect nitrogen conservation. If large amounts of ammonia are present in raw materials, some of this ammonia may be volatilized and lost before the microorganisms have had sufficient time to utilize and stabilize it, even though the C:N ratio is satisfactory for nitrogen conservation. This can be an important factor since much of the nitrogen loss occurs during the first few days of composting.

3.2.5. C/N ratio

According to Fig. 7, the average C/N ratio of the compost samples ranged from 13.2 to 18.2 (minimum value: 9.6, maximum value: 22.8). It is reported in the literature that mature compost must have a C/N ratio ranging between 10 and 20 (Kapetanios, 1990; Kapetanios et al., 1993). The lowest values (lower than 10) were recorded in the Municipality of Acharnes, while the highest ones (higher than 20) were determined in the Municipality of Nea Halkidona. These values were observed during the first cycles of the application in some households of the municipalities, when the householders were not fully familiar with the procedures that should be applied. For example, some householders used quite high quantities of feeding vegetable residues with a high content of nitrogen and low C:N ratio, a situation that affected the unobstructed development of the process and the achievement of an end product of desirable quality.

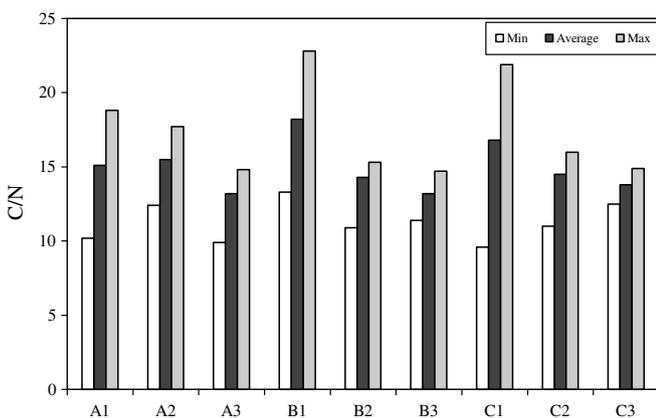


Fig. 7. C/N ratio of the compost samples.

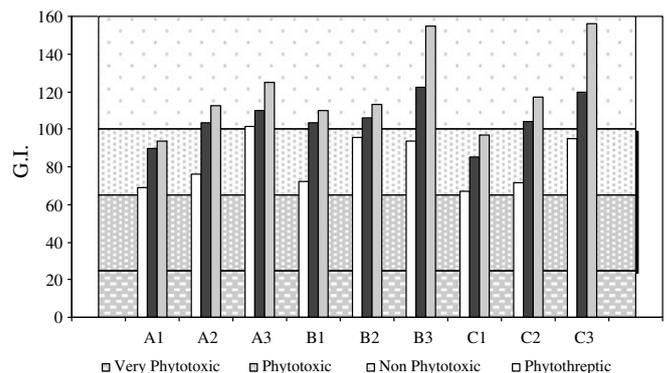


Fig. 8. Phytotoxicity effect of the compost samples.

3.2.6. Phytotoxicity

Determination of the level of phytotoxicity in the compost indicates if the organic matter is stabilized completely and, also, if the composting process has been developed smoothly (in most cases the generation of phytotoxins indicates unfavorable conditions during composting, such as inefficient aeration and high moisture level). In addition, phytotoxicity may be caused by the presence of heavy metals and specific organic substances (Zorpas, 1999).

Fig. 8 presents the phytotoxicity tests that were carried out on the compost samples. The phytotoxicity figure is divided into four discernible areas: 0–25 (very phytotoxic), 26–60 (phytotoxic), 61–100 (non-phytotoxic) and >101 (phytothreptic).

No phytotoxic effects were observed for any of the compost samples that were examined. A germination index under 65 shows a phytotoxic effect, but no phytotoxicity effect appears for values of germination index between 66 and 100. Finally, when the germination index exceeds 101, the product can be characterised as top-quality compost.

Comparing the results that were obtained related to the characterization of the compost samples, it is shown that:

- No significant variations were observed related to the characteristics of all the examined compost quality parameters among the three municipalities per composting cycle. Also, in all cases, the results concerning the quality of the household compost are in accordance with the qualitative values reported in the literature (Table 4).
- Concerning the qualitative characteristics: pH, moisture, carbon, nitrogen, and C/N ratio, no significant variations per composting cycle for each municipality were noted. Regarding the phytotoxicity tests, a progressive improvement in the compost quality within the development of the subsequent composting cycles at each of the three municipalities is shown. The compost that was produced in the first composting cycle was non-phytotoxic, while during the development of the next two composting cycles, the quality of the compost was further improved. In particular, during the second cycle, the compost samples were non-phytotoxic to phytothreptic and in the third cycle the majority of the compost samples were phytothreptic.

3.3. Other considerations

3.3.1. Cost of the manufacture and operation of the system

The cost of manufacturing of the household composting system is quite low and competitive with the cost of other systems that are

Table 4
Household compost characteristics

Parameter	Literature reference	Household compost analyses
Moisture content (%)	35–55 ^a 45 ^d >25 ^e	43–53
pH	6.5–8 ^a 8–8.6 ^b 6–8.5 ^c	7.0–8.7
Organic carbon (%)	18–35.5 ^a >18.0 ^{d,e}	19–32
Nitrogen (%)	1.1–1.9 ^b <2.0 ^{d,e}	1.1–2.3
C/N ratio	11.8–18.2 ^{a,b}	13.2–18.2

^a Kapetanios (1990).

^b WSDE (1994).

^c Hogg et al. (2002).

^d EC (2001a).

^e EC (2001b).

available in the market. Also, it must be mentioned that the cost per item is reduced as the number of items that are manufactured is increased. In particular, for the manufacture of more than 2000 systems, the cost per system is estimated to be lower than 250€. Additionally, the system operation cost is extremely low, since it includes only expenses for the provision of the additives. More specifically, the cost for the use of the natural zeolite per household on annual basis is estimated to be 3.5€, since the cost for the provision of the zeolite is about 100€/ton of zeolite and the required annual quantity of zeolite per household is about 35 kg (addition of 5% of zeolite/kg of organics × 700 kg of organics/household yr). The cost of the use of sawdust is negligible, since it is considered a waste stream and, consequently, should be provided free of charge.

Taking into account that: (i) the life time of the composter is estimated to be 10 yr; (ii) the annual quantity of compost that could be produced by a typical household (four persons) that uses a home composter is about 175 kg; (iii) the annual cost for the provision of zeolite is 3.5€; (iv) the maintenance and spare parts cost is about 1.8€/yr; it is expected that the annual cost for the provision and the operation of the system does not exceed 0.18€/kg of produced compost. This cost is outweighed by savings due to a reduction in costs associated with the management of the mixed household wastes (reduction in costs for collection and transfer of mixed waste for final disposal, in demands for the operation of the anti-polluting systems at landfill sites, in final disposal fees, etc.).

3.3.2. Non-quantitative benefits

A significant number of non-quantitative benefits can be obtained by the effective application of the home composting practice, such as:

- Reduction of the nuisance that occurs during the collection and transfer of the municipal solid waste.
- Lower burden of the landfill sites, in terms of quantity and polluting load, due to the reduction in the amount of municipal solid waste disposed, which results in an increase of their operation life cycle.
- Generation of leachates at landfill sites with reduced organic load due to the decrease in the organics that are disposed.
- Reduction of the air emissions from landfills in qualitative and quantitative terms (concentrations of carbon dioxide and methane).
- Production of a product with added value that could be used for landscaping or for agricultural purposes, such as soil fertilizer, improvement and conditioner – reduction of the use of synthetic fertilizers.
- The application of the practice of the separation of organics at source offers the opportunity of a high quality “clean” feedstock for composting and the prospect of an uncontaminated end-product, compared to the organic material derived from central mechanical sorting plants.
- The separate collection and simultaneous composting of the kitchen organic waste fraction by the householders facilitates a reduction in the frequency of collection of the residual household waste fraction. This is an important consideration, especially in Southern European and other Mediterranean countries where the climatic conditions demand more frequent collection of easily degraded wastes.

3.3.3. Impacts to actors involved

The outcome of the pilot implementation of the home composter has a positive impact on all the actors involved in the field of the household solid waste generation and management. In particular:

- (i) *Citizens/householders*: Their environmental awareness increases, they take more initiatives and make more effort to protect the environment, they learn the practice of simultaneous separation/composting of biodegradable household waste as a common daily activity, they have a product with added value originating from their waste, they participate actively in material recycling schemes and they acquire a sense of responsibility for their waste.
- (ii) *Local authorities*: They are provided with an effective tool in order to re-organize the existing practices that are applied for the household waste management according to the principles and the priorities of the European and national environmental policy and legislation. This results in: (a) monetary savings (from the reduction of the expenses for the collection and transfer of the mixed municipal waste to the landfills as well as from the utilization of the produced compost; (b) limitation of the annoyance occurring during the collection and transfer of waste to the landfill sites; and (c) improvement of the entire environmental image of the municipality/community.
- (iii) *Private companies*: Private companies dealing with the trade of products for agricultural applications could include the compost produced via household composting in the products that they are selling.
- (iv) *Public authorities/decision and policy makers*: The application of separate collection/composting of the household biodegradable organic waste on a large scale will contribute to the achievement of the quantitative national targets concerning the diversion of the biodegradable organics from landfills. In addition, by incorporating this practice in the existing solid waste management schemes, the principles and the priorities of the European and national environmental policy and legislation are enforced in practice providing tactile results.

4. Conclusions

The in-home testing of a new household composter for the production of compost from biodegradable household waste separated at the source indicated its effective operational performance in practice. The compost that was produced in the households was characterized by high quality, as confirmed by the results obtained from the analyses carried out concerning the pH level, moisture, organic carbon content, nitrogen content and C/N ratio. These results are in accordance with the quality standards set for its use.

Also, the compost that was produced in the first composting cycle was non-phytotoxic, while the quality of the compost was further improved during the development of the next two composting cycles (during the second cycle, the compost samples were non-phytotoxic to phytothreptic and in the third cycle the majority of the compost samples were phytothreptic).

Only in few cases (in the first cycle of the pilot implementation), the quality of the compost was not high due to operational prob-

lems that were observed during the process development (some householders were not familiar with the use of the composter yet), but when these operational problems were solved, the compost that was later produced was of high quality.

Finally, the pilot implementation of the new composter at the households indicated the high interest and response of the citizens to get involved in the management of their waste.

Acknowledgments

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