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Assessment of the Characteristics of the Municipal Solid Waste Compost in Lebanon

Rana Sawaya[1*], Jalal Halwani[1], Nada Nehme[2], Hiba Alawiye[3], Walaa Diab[3]

[1]Water & Environment Science Lab, Lebanese University, Tripoli, Lebanon
[2]Faculty of Sciences, Lebanese University, Hadath, Lebanon
[3]Faculty of Agriculture Engineering and Veterinary Sciences, Lebanese University, Dekwaneh, Lebanon
Email: *rana.sawaya1313@gmail.com, *rsawaya@live.com

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Abstract

Waste management is crucial due to the fast increase of human population, causing an increase in solid waste generation which if not properly managed causes environmental problems. Around 57% of the wastes generated from homes are made up of green material (fruits, vegetables…). Thus, reusing and recycling green wastes through composting is one way of reducing the waste load to landfills. Composting is the transformation of raw organic materials into organic soil amendments that provide nutrients to crops and enhance the tilth, fertility, and productivity of soils. Aerobic windrow composting system at Sukomi Greensite facility located at Karantina is performed, where materials biodegrade under controlled conditions to produce compost. However, assessment of the quality of the compost is fundamental in order to determine its usages. Thus, regular testing of physical, chemical and biological parameters was performed for adequate monitoring purposes. The basic objective of this study was to determine the characteristics of the Lebanese municipal solid waste compost on a yearly basis and compare these characteristics amongst the years. Hence, each parameter was tested and compared to the BNQ international Canadian standards for proper classification of the compost and adequate identification of its usages. The preliminary data obtained were statistically diagnosed through principal component analysis by Spadv55 software. All the data reflected the normal content value of the studied parameters with minor differences between the years except for year 2007 which demonstrated higher levels of Potassium, Phosphate, Lead and Cadmium. The characteristics of the compost enabled it to be used as a soil amendment on all types of agricultural and landscape commodities at the adequate dosages and proper timing. This data will additionally reflect the efficiency of the solid waste management practices adopted via highlighting the importance of the implementation of the integrated solid waste management practices.

Keywords

Composting, Organic Material, Lebanon, Contamination, Solid Waste Management

1. Introduction

The worldwide management of municipal solid wastes is an ongoing challenge and a grave problem especially in urban cities whereby urbanization, population growth as well as dwindling land areas are all aggravating the corresponding issues and pushing them to the verge of national crisis; The world bank presented an estimate pertaining to an increase the global waste generation rate from 2.01 billion tonnes in 2016 to reach around 3.40 billion tonnes in 2050 (SweepNet, 2014). As a matter of fact, numerous Asian countries (China, Indonesia, Pakistan, Bangladesh, Japan…) have been experiencing a notably hasty economic development coupled with social change which influenced the urban life to a great extent. Thus, the latest UN projections reveal that Asia's population will encompass more than 1.25 billion people by year 2030, creating a detectable load on urban areas subsequently and increasing the amount of wastes to be disposed of. Significant increase in waste generation from domestic and commercial activities was detected in developing countries especially Lebanon which underwent a series of rapid changes over the last decades (Halwani et al., 2020). As a result of the deficiency in environmental awareness and legislative framework including lack of laws enforcement, the foreseen waste generation rate is expected to increase from 1.57 million tons in 2009 to 2.4 million tons by 2035 (SweepNet, 2014). Municipal solid waste (MSW) constitutes about 90 percent of the total solid waste stream produced in Lebanon. Hence, more than half of the waste stream is composed of putrescible (55%), the remaining components belong to the potential recyclables category (29%) and the rejects category (16%) (Sawaya et al., 2021). In other words, it can be said that the major portion of the waste stream consists of biodegradable organic matter characterized by high moisture content and subsequently low calorific value which render the incineration treatment option unfeasible. Also, Obnoxious and possibly toxic decomposition products from organic wastes contaminate the air, water and land resources. Thus the most important way of managing the high load of organic material through resource recovery is through composting. Composting is considered as one of the most environmentally friendly alternatives which enable the transformation of raw organic materials into organic soil amendments that provide nutrients to crops and enhance the tilth, fertility, and productivity of soils (Azim et al., 2018). In other words, composting of the solid waste and using it on the land is the best way of solid waste disposal. This will reduce the waste volume transported to the landfill and will increase its life, particularly since more than 50% of the average municipal solid waste stream pertaining to low- and middle- income countries could be readily composted (Rahman et al., 2020; Barrena et al., 2014). In Lebanon, a minor portion (30%) of the organic wastes of Greater Beirut area are composted due to the limited capacity of the composting facility located in Karantina area. The aerobic windrow composting system was adopted whereby the organic waste stream proceeds to the fermentation shed where materials biodegrade under monitored moisture, temperature, and aeration conditions to produce compost used in agriculture and landscape. However, the crucial criterion that determines the usage of compost is its quality which depends on two key factors related to the original raw material as well as the technology adopted. A stable product void of phytotoxic compounds is required for subsequent application as growth media. Several parameters should be studied for an adequate assessment of the quality of the product. The importance of studying the physiochemical parameters of compost (pH, electrical conductivity, nutrient content…) is mainly interrelated with the characteristics of the raw feedstock rather than the process itself. The fact that the compost is originating from municipal solid waste, thus it inevitably contains some heavy metals such as zinc, copper, boron, mercury, nickel, cadmium, lead… Thus, a regular monitoring for the heavy metals content is of great necessity as an excessive application can be toxic to plants and might affect the microbiological characteristics of soil such as the soil micro-biota which in turn have an essential role in making nutrients available to plants. Furthermore, heavy metals might enter the food chain, contaminate water and cause adverse effects on human health (Rawat et al., 2013). In this study, an exhaustive analysis of physiochemical, microbiological and heavy metals parameters was conducted for an 11-year period in order to determine the quality of the substrate. Since this is a unique experience of production of municipal solid waste compost at an industrial level in Lebanon, thus the basic objective of this study is to determine the characteristics of the Lebanese municipal solid waste compost during the ten-year period of its production (2005-2016) to detect any changes if any in terms of parameters and then compare them to selected international standards. Furthermore, it will define its usages as a soil amendment and/or fertilizer replacement on best fit crops and ornamentals.

2. Materials and Methods

2.1. Site Description

The site under consideration is located in Bourj Hamoud. The proposed project area is located in a region that is classified with a typical Mediterranean climate, where the rainy season falls between October and April. Onshore Southwest winds from the adjacent Mediterranean Sea affect the area most of the year. The meteorological data were retrieved from the Central Administration of Statistics official website (www.cas.gov.lb) and were recorded at the Beirut International Airport station (33.822714, 35.495628). The study area is characterized by hot dry summer and relatively mild wet winter. The south of the proposed site location includes several industrial facilities. From the west, the Port of Beirut is located, and the Beirut River is distant by 335 m.

The site lies in an alluvial plane with Quaternary deposits forming the water basin for Nahr Beirut.

The dominant geologic units are "Ramleh" deposits. It consists of sand and larger-sized grains dominated by rounded shape. Coarse soil grains (silt-sized, sand-sized and larger) have different shape characteristics and surface roughness depending on the amount of wear during its transportation by different sources like water, wind or ice, or after crushing to manufactured aggregates. On site, the investigation shows an alternating black, brown, grey and dark grey sand with gravel. Structurally, minor faults are located 2 km to the west direction. Patches of dark color deposits occurring essentially below 6 m depth in the boreholes could be indicative of the presence of organic and leachate deposits from landfill contaminants. Underground water was encountered below and above natural ground level (i.e. at level −3.11 m to +1.15 m) (Nader, 2014).

2.2. Compost Production

The study was carried out in the experimental composting plant referred to as greensite situated in Karantina area pertaining to Beirut district (**Figure 1**). As previously mentioned, organics which constitute around 55% of municipal solid wastes are sorted apart as a prepolishing phase prior to sending them for composting at greensite composting plant whereby they pass via a magnetic separator for a second time in order to remove any source of tin, metals which will allow for the accumulation of heavy metals in the final product for obtaining fine compost product. As a matter of fact, the capacity of the plant is 300 tons per day.

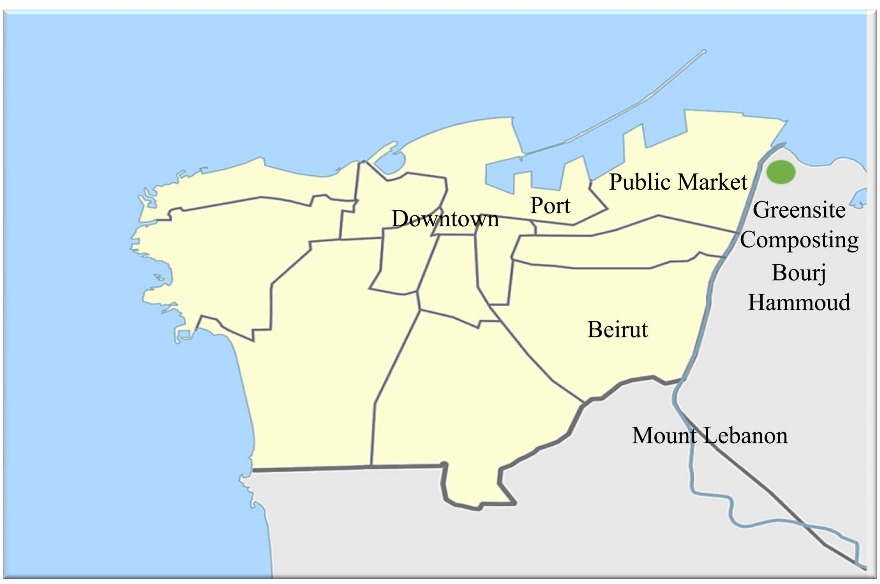

Figure 1. Location map of greensite composting plant.

Composting method used is the turned windrow system whereby organic waste is formed into rows of long piles called "windrows" and aerated by turning the pile periodically via aerators. The pile is large enough to generate sufficient heat and maintain temperatures, yet small enough to allow oxygen to flow to the windrow's core.

The raw organic material (feedstock) is received from the sorting plants and delivered to the greensite receiving area where it is fed on a drag conveyor inside the fermentation hangar. The feedstock is hereby distributed by a chariot verseur all along the hall (180 m) to constitute the windrow over a period of 6 days. This composting system consists of windrows that have a ~160 m length, 6 to 7 m width, and 2 to 3 m height. The composting hangar consists of 11 piles the first 6 piles are in the fermentation stages whereas the remaining 5 are attributed to the maturation stages. The aeration and turning operations during the composting process are carried out as per a set weekly schedule. Turning is performed via turner/loader for piles 1 to 10. Whereas intensive aeration via aerators is performed for the last two piles (10 & 11) to supply enough oxygen for microbial biomass.

Adequate spacing of about 1.5 m to 2.5 m is maintained from both sides of the windrow to ensure the adequacy of the operation.

Following every pile aeration or turning, a reshaping using the loader machine is performed to maintain the windrow shape, and to minimize the space occupied by each windrow for adequate operational ground space between the piles. Compost operation at greensite consists of an 11-week (72 days) turned windrows composting system in a closed hangar (**Figure 2**). As a matter of fact, the total amount of putrescibles entering the composting plant from years 2005 till 2016 amounts to 1302847.60 tons.

2.3. Sampling and Analysis

The major type of sampling used in compost samples' collection is the composite sampling method which is based on the collection of numerous grab samples

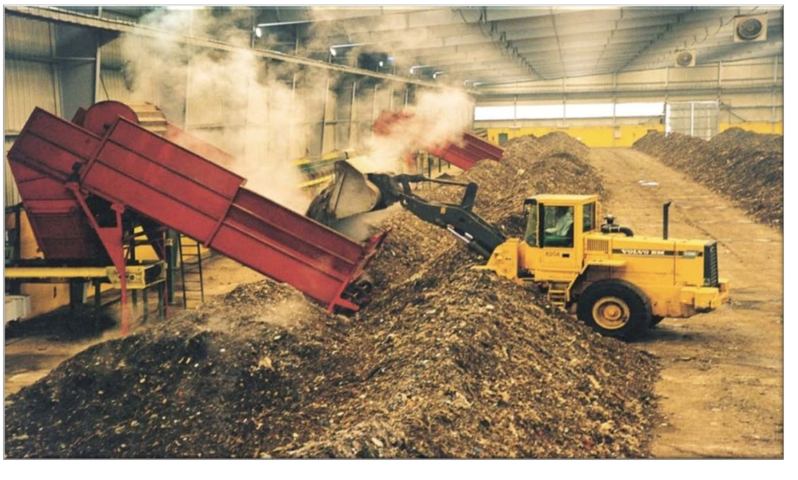

Figure 2. Aerobic windrow system at greensite composting plant.

taken from different locations at various intervals over a certain period of time in order to obtain a representative sample. This type of sampling provides a reliable estimate of the average characteristics. Our study mainly encompasses the polished compost samples which are collected for analysis prior to dispatch. Prior to collection of the sample, the auger was disinfected using hot water and any available disinfectant (e.g. sannitol 5%). Thus, for obtaining a representative polished sample, one composite sample from 4 different locations from the polished heap at the bunker was collected on a weekly basis at a depth of 1 m (**Figure 3**).

In order for the compost to be used as a growing media, it should meet stricter quality criteria than compost intended for other usages such as reclamation of degraded soils or as landfill cover. Hence, for a proper assessment of the mode of its usages, it is of extreme importance to assess its physical, chemical and microbiological characteristics. Furthermore, ensuring the absence of toxic components including heavy metals is imperative for rendering compost a commercially viable product.

This study was performed for a period of ten consecutive years (2005-2016) whereby analysis for every polished pile and on a weekly basis was performed on all the aforementioned characteristics. The physical/chemical properties analyzed were: pH, EC, Salinity, Nitrate (NO_3^-), Phosphate (PO_4^{3-}), Ammonia-N (NH_3-N), Moisture Content (MC), Organic Matter (OM), Nitrogen (N), C/N. The microbiological parameters covered mainly the Total Coliforms and Salmonella. The selected metals are: Lead (Pb), Chromium (Cr), Cadmium (Cd), Copper (Cu), Zinc (Zn), Nickel (Ni), Potassium (K), Magnesium (Mg), Manganese (Mn), Calcium (Ca) and Mercury (Hg).

In the laboratory, samples were analyzed according to established methods and procedures derived from the "Test Methods for the Examination of Composting and Compost" (TMECC, 2000). The method of analysis along with the reference method are demonstrated in the below **Table 1**.

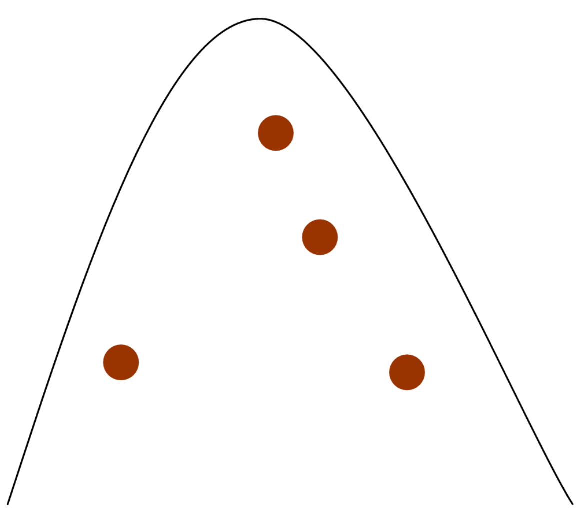

Figure 3. Sampling points of the polished compost heap.

Table 1. Analysis methods of the parameters.

Laboratory Analysis	Instrument/Mode	Reference Method
pH Value	pH meter	SM 4500-H+ B
Electrical Conductivity	Conductivity Meter	SM 2510 B
Phosphate	Spectrophotometer	SM 4500 PE HACH 8048
Nitrogen	Kjeldahl	SM 4500-N_{org} TMECC 04.02A
Ammonia Nitrogen as NH_3 Titrimetric Analysis	Distillation and Titration	SM 4500-NH_3 B & C
Nitrate	ISE for Nitrate	SM 4500 NO_3_D TMECC 04.02B
Heavy Metals	AAS	TMECC 04.12B TMECC 04.13B AOAC 999.11 AOAC 958.01C.
Calcium	Titration	SM 3500-Ca B
Moisture Content	Oven	SM 03.03-A 7
Organic Matter	Furnance	ASTM D-2974-87 C TMECC 05.07A
Fecal Coliform	Membrane Filtration	SM 9222 D
Salmonella	Enrichment and Quantification	SM926OD

TMECC: Examination of Composting and Compost, SM: Methods for the Examination of Water and Wastewater, HACH: certified procedures accepted by the USEPA for use in the analysis of water and wastewater, AOAC: Association of Official Analytical Chemists for official methods of analysis, ISE for Nitrate: Ion-Selective Electrode, AAS: Atomic Absorption Spectrophometer.

It is worthnote mentioning that the basic objective of this study is to: determine the characteristics of the Lebanese Municipal Solid waste compost during the 11-year period of its production (2005-2016), detect any changes if any in terms of parameters, and compare them to selected international standards.

2.4. Statistical Analysis

As the quality of the compost is multifactorial, multivariate analysis was applied as follows:

1) Hypotheses testing:

In this section, evaluation of the available data was performed in order to detect the change in the characteristics of the Lebanese Municipal Solid waste compost during the 11 year period. Thus, the main aim was:

- Evaluating the characteristics of the solid waste compost on a yearly basis;
- Comparing these characteristics among years.

On the basis of such objectives, hypotheses were developed and which encompassed testing the presence of any significant difference of each and every parameter between the years.

Data were analyzed using statistical tests including Kruskal-Wallis test using SPSS 23 (SPSS Inc, Chicago, IL, USA) in order to determine the significant difference in the content values for the different parameters across years.

The Kruskal-Wallis test is a nonparametric test used to compare three or more independently sampled groups on a single non-normally distributed continuous variable (Kruskal & Wallis, 1952).

Since the main assumption to use Kruskal-Wallis is to have samples that they are not normally distributed, Kolmogorov-Smirnov test and Shapiro-Wilk tests are used to examine the normality of each parameter (Mishra et al., 2019).

All parameters revealed a p-value = 0.000 which is less than 0.05 indicating that the data is not normally distributed.

After application of Kruskal-Wallis Analysis, results showed that the content values of each parameter are statistically different over years excluding Fecal Coliform and Salmonella parameters which maintained similar values throughout the years.

2) Validation

Each parameter has his international standard values that should be respected. Therefore, it is of utmost necessity to verify if our data is in conformity with these standards. For this, confidence interval of the mean content value for each parameter was calculated and represented in its upper and lower values (**Table 2**).

3) Principal Component Analysis (PCA)

PCA is one of the most widely method used to reduce the dimensionality of data by conserving as much variability as possible by finding new factors that are linear combinations of the original variables.

In order to visualize the data in a reduced space, Principal component analysis (PCA) was applied using Spadv55 software. As a matter of fact, there are several statistical methods that can summarize the information contained in a data matrix. Among these, Principal Component Analysis (PCA) allows to:

a) Reduce the number of variables.

b) Detect a structure in the relations between variables.

3. Results and Discussions

The below represents a thorough assessment of all types of compost parameters with their interpretations.

3.1. Physiochemical Parameters Assessment

Sukomi's compost underwent regular physical, chemical and biological analysis during the whole biodegradation period to ensure the best quality of compost end product. The results were evaluated based on the National Canadian standards, BNQ. It is worth mentioning that MSW compost was not distributed to

Table 2. Table representing the yearly parameters.

Parameters	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	BNQ Standards
pH	7.12	6.40	7.50	7.33	7.39	7.41	7.46	7.38	7.30	7.14	7.30	7.34	**6.5 - 8.5**
EC mS/cm	5.12	5.03	4.20	5.54	4.86	5.03	4.92	5.04	4.99	5.31	5.14	5.09	**5 - 6**
Zinc mg/Kg	439	326	110	439	430	456	463	461	459	462	458	454	**500 - 1850**
Lead mg/Kg	134	116	468	173	184	181	152	151	152	153	150	149	**150 - 500**
Chromium mg/Kg	26.6	29.1	0.3	33.0	22.7	22.1	40.4	40.0	39.4	40.6	39.8	37.7	**210 - 1060**
Cadmium mg/Kg	1.00	0.63	36.7	1.48	1.14	1.01	0.72	0.70	0.70	0.71	0.72	0.71	**3 - 20**
Moisture content%	51.7	52.4	49.3	48.6	48.2	47.3	47.6	47.4	47.4	47.3	47.8	47.7	**40 - 60**
Organic matter %	57.5	57.2	53.9	54.0	53.3	52.0	52.2	52.0	52.1	52.2	52.6	52.7	**35 - 55**
C/N ratio	19	19	17	17	17	16	16	15	16	16	16	17	**20 - 25**
Salinity g/L	2.21	2.17	1.84	2.39	2.09	2.15	2.15	2.16	2.13	2.28	2.24	2.19	**NA**
Nitrate mg/L	37.9	70.0	29.4	71.5	107.5	65.7	41.7	55.0	51.5	50.3	62.1	66.2	**NA**
PO_4^{3-} mg/L	4.57	3.76	4.46	3.39	2.35	1.97	2.39	1.99	1.99	1.95	1.96	1.92	**NA**
Calcium mg/L	853	1028	856	897	850	810	803	748	752	751	826	876	**NA**
NH3-N mg/L	188	160	198	196	185	169	171	176	170	219	249	247	**NA**
Potassium g/L	0.30	0.25	139	0.29	0.31	0.30	0.25	0.24	0.24	0.24	0.24	0.24	**NA**
Magnesium mg/Kg	1920	1760	2610	2240	2366	2458	3140	3150	3127	3159	3121	3113	**NA**
Nitrogen %	1.42	1.42	1.40	1.42	1.40	1.45	1.49	1.54	1.48	1.47	1.44	1.44	**NA**
Manganese mg/Kg	**103**	77	110	96	95	94	82	82	82	82	82	81	**NA**
Fecal Coliforms MPN/g	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	**<1000**
Salmonella col/g	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	**<3**

farmers unless it met all the quality requirements related to product safety and market claim. Hence, each parameter was tested and compared to the selected standards for proper classification of the compost and adequate identification of its usages (Table 2). The confidence interval of the mean value for each parameter was calculated and represented in Table 3.

3.1.1. pH

pH which is a measure of the acidity or alkalinity of the compost is considered as a one of the most crucial chemical indicators of the maturity of compost. Knowing the pH is vastly important as compost application to the soil can alter the soil pH and subsequently affect the availability of nutrients to plants. The pH can be subjected to a certain decrease in the initial stages of composting as a result of organic acids releasing during the decomposition of simple organic substrates as well as volatilization of ammonia. Thus, the ongoing increasing trends of ammonia gas emissions to ambient air correspond in its turn to an increase in the temperature of the compost pile (35˚C - 60˚C) and a resultant alkaline pH value (7 - 8.8) (Rahman et al. 2020; Mandal et al., 2014).

Table 3. Confidence Interval of the mean for each parameter.

	Lower Bound	Upper Bound
PH	7.2762	7.3347
EC	4.9261	5.2943
Moisture	48.125	48.441
Salinity	2.1514	2.182
Organic	53.0569	53.3846
Potassium	0.2626	0.2708
Nitrate	52.6307	57.5235
PO_4^{3-}	2.5425	2.8083
Calcuim	807.0291	829.0151
NH_3N	189.9140	195.5635
Magnesuim	2504.4075	2648.4008
Manganese	88.0207	90.1847
Zinc	442.4251	451.1398
Lead	152.8369	156.6699
Chromium	33.3060	34.9672
Cadmium	0.8682	0.9392
Nitrogen	1.4455	1.4581
CNratio	16.5545	16.7574

The international standard values for PH content in the compost vary between 6.5 and 8.5. In the studied compost the range is between 7.27 and 7.33 which indicates a mature compost.

3.1.2. Electrical Conductivity

The electrical conductivity which is a measure of soluble salt content is an important determinant of the compost quality since high salt levels can inhibit seed germination and plants especially when the compost is being used as a growing medium. In case compost is used as a soil amendment, then the desired ranges may not apply as a result of the diluting effect of the compost-soil mix. The initial stages of composting are characterized by accelerated initial microbial activity and mineralization increasing the soluble salt content and hence, the EC levels. In later stages, the soluble salts form complexes with the humic fractions causing a subsequent decrease in the amount of mobile free ions and EC (Rahman et al., 2020; Rawat et al., 2013).

It can be said that EC is a prime parameter in determination of the chemical properties and nutrition level of compost (Manohara et al., 2017).

The international standard content for EC in the compost varies between 5 and 6. In the studied compost the range is between 4.92 and 5.29 which is acceptable and indicate more or less mature compost.

3.1.3. Organic Matter Content

Organic matter is an indication of the amount of carbon based material in the compost. This importance of this parameter lies in maintaining soil structure, water holding capacity and nutrient availability. A high organic matter level (>60%) signifies an immature compost which can play an inhibitory role with respect to plant growth when mixed with soil. Furthermore, a low organic matter content (<30%) will have no effect in improving the soil quality (Rahman et al., 2020). As a matter of fact, the relationship between organic matter, temperature and time of composting is inversely proportional as the total organic matter will decrease during the composting process as a result of mineralization of organic matter by microbes (Ameen et al., 2016).

The percentage of organic content should be between 35% and 55% to respect the international standard and in our compost it is between 53% and 53.4% which is acceptable.

3.1.4. Moisture Content

The optimum moisture content for composting mass should range from 45% to 60%. Material should feel damp to touch. Low moisture content will result in poor bacterial activity and subsequently poorly stabilized composts. Whereas a high moisture content will lead to anaerobic zones with odor production, nutrient leaching and slower decomposition process (Saha et al., 2010).

The percentage of moisture content should be between 40% and 60% to respect the international standard and in the studied compost it is between 48.1% and 48.44% which is acceptable.

3.1.5. C/N Ratio

The C: N ratio is a determinant of the extent of compost maturity (Rahman et al., 2020). Carbon and nitrogen are used by the microbes in their metabolism to produce energy and in the synthesis of new cellular material. C/N ratio varies depending on the feedstock material. Woody materials have a high C/N ratio, while materials such as fresh grass clippings have a lower C/N ratio (Paul & Geesing, 2009).

As a matter of fact, the C/N ratio is known to decrease during the composting process. However, the rate of the decrease is aligned with the ratio in the initiation of the process as well as on the composting material (Azim et al., 2018). A very low C/N ratio will cause the loss of ammonia through the volatilization process. Whereas a very high C/N ratio will promote immobilization of plant-available nitrogen and as a result of the limited N, the decomposition process might slow down (Toscano et al., 2013).

The ratio C/N should be between 20 and 25 to respect the international standard and in the studied compost it is between 16.55 and 16.75 which is below the standard. However, Jiménez and García (1991) estimated that a ratio even as low as 15 can characterize mature compost. Moreover, a study performed by Namkoong et al. (1999) clarifies that composts characterized by a ratio of 10 to 15 can be stable as this fact is dependent on the initial materials used. In this case the composted material mainly consists of organic food wastes and greens which have a lower C/N ratio than woody stuff. In addition to the above, the C/N ratio in compost is compared to that of the humic soil which is close to 10 (Sharma, 2019).

3.1.6. Nutrients Content

The concentration of nitrogen, phosphate, potassium and nutrients in MSW compost is mainly dependent on the feed stock used and stage of maturity (Rahman et al., 2020). These parameters provide an understanding of the compost characterization which is to be used as a fertilizer (Manohara & Belagali, 2016).

Nitrogen is one of the most crucial elements for plant growth and is a major constituent of chlorophyll which provides the green color to plants. It has been observed that the Nitrogen concentration in municipal solid waste compost was found to increase with time as Carbon is utilized by microorganisms (Wolkowski, 2003). The percentage of Nitrogen in our compost it is between 1.45% and 1.46%.

Phosphorous is a component of the complex nucleic acid structure of plants which is known to regulate protein synthesis. Its importance lies in plant's cell division, new tissue generation and in complex energy transformations in the plant. Hence, when phosphorous is added to soils deficient in this element, it enhances root growth, winter hardiness, stimulates tilling, and often accelerates maturity in plants (Kammoun et al., 2017). Compost is known to hold optimum phosphorus concentrations necessary for plant growth (Khater, 2015). The concentrations of phosphate in the studied compost varied between 2.54 mg/l and 2.81 mg/l.

Potassium is an essential element known to promote plant growth, mainly the color and vigor of plants. Also, it aids plants to resist diseases and to survive through rough weather conditions such as cold and drought (Razaq et al., 2017). The concentrations of potassium in the studied compost ranged between 0.26 g/l and 0.27 g/l.

It is worth mentioning that the macronutrient content of most of the composts is considered low in comparison to most commercial fertilizers. As a matter of fact, composts are generally regarded as an excellent source of micronutrients such as calcium and Magnesium which are essential for growth of microbes. In addition to that, these parameters determine the fertility potential of the compost mainly at the maturation stage (Manohara et al., 2017). The calcium content in the municipal solid waste compost was observed to range between 807 mg/l and 829 mg/l. The magnesium content varied between 2504 mg/kg and 2648 mg/kg.

In order for the crops to acquire the necessary fertilizers' requirements for maximizing their growth, compost application should be coupled with fertilizers incorporation to the soils for obtaining optimal results.

3.2. Heavy Metals Concentration

Heavy metals contamination in MSW composts is another crucial quality parameter which is essential for the protection of soil and water resources from pollution (Saha et al., 2010). High levels of heavy metals in composts such as boron, zinc, copper, and nickel might impair plants and crops growth. Their presence is required in small amounts. However, the presence of other heavy metals such as arsenic, cadmium, lead, and mercury are of prime concern due to their potential to accumulate in the soil with their subsequent contamination effects on both human and animal food chains (Peña et al., 2020). The Zinc content in the compost ranged between 442.42 mg/Kg and 451.13 mg/Kg which is below the permissible limits of the international BNQ standards (500 mg/Kg and 1850 mg/Kg). The content of chromium ranged between 33.3 mg/Kg and 34.95 mg/Kg which is way below the international standard range (210 mg/Kg and 1060 mg/Kg). The content of cadmium varied between 0.86 mg/Kg and 0.93 mg/Kg which is below the international standard range (2 mg/Kg and 3 mg/kg). Finally, the lead concentration in our compost ranged between 152.83 mg/kg and 156 mg/kg which falls within the permissible international limit range (150 mg/Kg and 500 mg/Kg). It can be detected that there is no risk of heavy metals contamination from our compost which is considered safe for application.

3.3. Bacteriological Study in Compost

Municipal solid waste compost might contain harmful pathogenic bacteria as mixed waste was processed for preparation of compost. The harmful pathogens such as Fecal Coliforms and Salmonella can have serious effects on the health of individuals as well as the personnel handling the MSW during the waste segregation and transportation processes (Rahman et al., 2020). However, the analyzed compost samples were not contaminated with pathogenic bacteria. This is mainly attributed to the rise of temperature during the composting process. As a matter of fact, a temperature between 55˚C and 70˚C maintained for at least 10 days is sufficient to provide a pathogen-free, high quality final product. Below 55˚C some organisms which are hazardous to humans, plants and animals might be present in the end product. Above 70˚C only few microbial species can operate (Omrani et al., 2004).

Yearly data for 18 composting parameters for a 12-year period (from January 2005 till April 2016) have been used in this study. The characteristics of compost described by the 18 parameters vary from year to year. This raises the question: Is there an identifiable pattern in these variations, or is the variability purely random?

Principal Component Analysis (PCA) was applied on the data to identify a number of components that affect the compost parameters over years.

The eigenvalues for the first 12 principal components are shown in Table 3.

Kaiser's rule is based on the principle of keeping components with eigenvalues greater than 1. Thus, Kaiser's rule leads to select four axes, explaining 91.5% of the total inertia. The first component accounts for more than 40% of the total inertia, strongly dominating the total inertia and the second component accounts for more than one third of the total inertia. The first two components together make up 76.5% of the total inertia. Afterward, the individual component contributions drop below 8%. In reality and as shown in Table 4, we can simply select the first two axes here as these two axes retain over 70% of the inertia which is very good. With the first two axes, we have a reduced space that can allow a simple visualization of data without suffering of deformation of data cloud.

PCA provides principal components, which are new artificial variables defined by linear combinations of original variables which should interpret now according to original variables. To do this, linear correlation coefficients noted as r(c, Xj) between principal components c and original variables Xj were computed and the results are represented in Table 5. The largest correlation coefficients (in absolute value) close to 1 are those of interest. By fixing a limit value of 0.75 for the correlation, the variables which determine the axes are:

- ***Axis 1***: The first principle component (PC1) accounts for 44.2% of the variance, which is negatively correlated with Potassium, Phosphate, Lead and Cadmium and positively correlated with EC, Manganese, Zinc and Chromium.
- ***Axis 2***: The second principle component (PC2) accounts for 32.3% of the variance, which is negatively correlated with Moisture, Organic content and C/N and positively correlated with PH and Magnesium.

Table 4. Eigenvalues of the first 12 principal component vectors.

Number	Eigenvalue	Percentage	Cumulative percentage
1	7.96	44.2	44.2
2	5.81	32.3	76.5
3	1.48	8.21	84.8
4	1.21	6.74	91.5
5	0.77	4.30	95.8
6	0.39	2.15	97.9
7	0.17	0.94	98.9
8	0.12	0.68	99.6
9	0.07	0.42	100
10	0.00	0.02	100
11	0.00	0.01	100
12	0.00	0.00	100

Table 5. Variable–factor correlations.

Variable	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
pH	0.108	0.767	0.294	0.08	−0.499
EC	0.760	−0.479	0.038	−0.260	−0.172
Moisture	−0.571	−0.760	−0.247	−0.105	0.058
Salinity	0.734	−0.483	0.049	−0.313	−0.185
Organic content	−0.511	−0.808	−0.184	−0.143	−0.059
Potassium (1:5) g/L	−0.873	0.461	0.054	−0.110	−0.018
Nitrate	0.320	−0.366	0.625	0.525	0.210
PO_4^{3-}	−0.809	−0.417	−0.193	−0.173	−0.292
Calcium	−0.459	−0.732	0.181	−0.015	0.321
NH_3-N	0.159	0.185	0.601	−0.723	0.128
Magnesium	0.487	0.801	−0.013	−0.237	0.205
Manganese	0.781	−0.532	0.021	0.165	−0.253
Zinc	0.961	−0.161	−0.008	0.036	−0.163
Lead	−0.812	0.528	0.168	−0.013	−0.109
Chromium	0.901	−0.073	−0.215	−0.251	0.196
Cadmium	−0.875	0.454	0.065	−0.106	−0.035
Nitrogen	0.318	0.655	−0.613	0.015	0.126
C/N	−0.622	−0.756	0.116	−0.094	−0.083

The third and fourth axes are not strongly correlated with any variable, so they shall be disregarded.

It is worthnote mentioning that Figure 4 depicts the variables correlation circle which summarizes the correlation between variables and factors. It can show the positively correlated variables which are grouped together and the negatively correlated variables which are positioned on opposite sides of the plot origin (opposed quadrants). Variables that are away from the origin are well represented on the factor map.

Indeed, observations with the largest negative coordinates on the horizontal axis correspond to years where the composts are with high content value of Potassium, PO_4^{3-}, Lead and Cadmium which are in opposition with the years where the compost contain high values of EC, Manganese, Zinc and Chromium. As for the observations along the vertical axis, they demonstrate the years where the composts with high moisture, organic contents and high C/N ratio values are in opposition with years where the compost with high PH values and Magnesium contents.

A graphical representation of the points (years) onto plane 1, 2 by their Coordinates is shown in Figure 5. This will allow us to determine the mode of

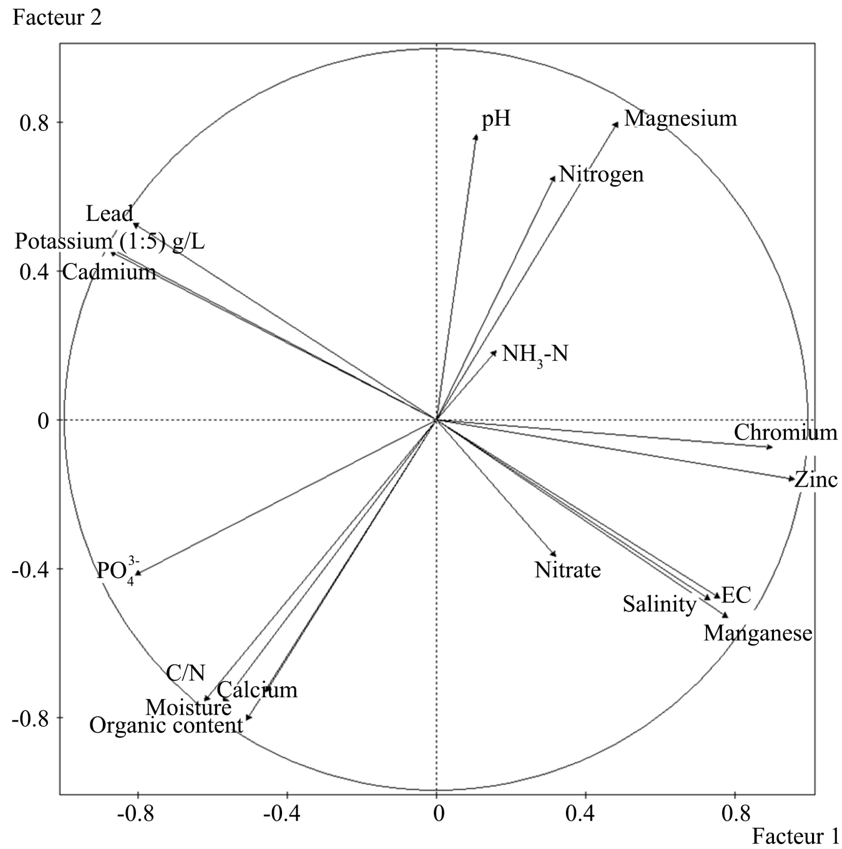

Figure 4. Correlation plot: Variable representation onto plane 1, 2.

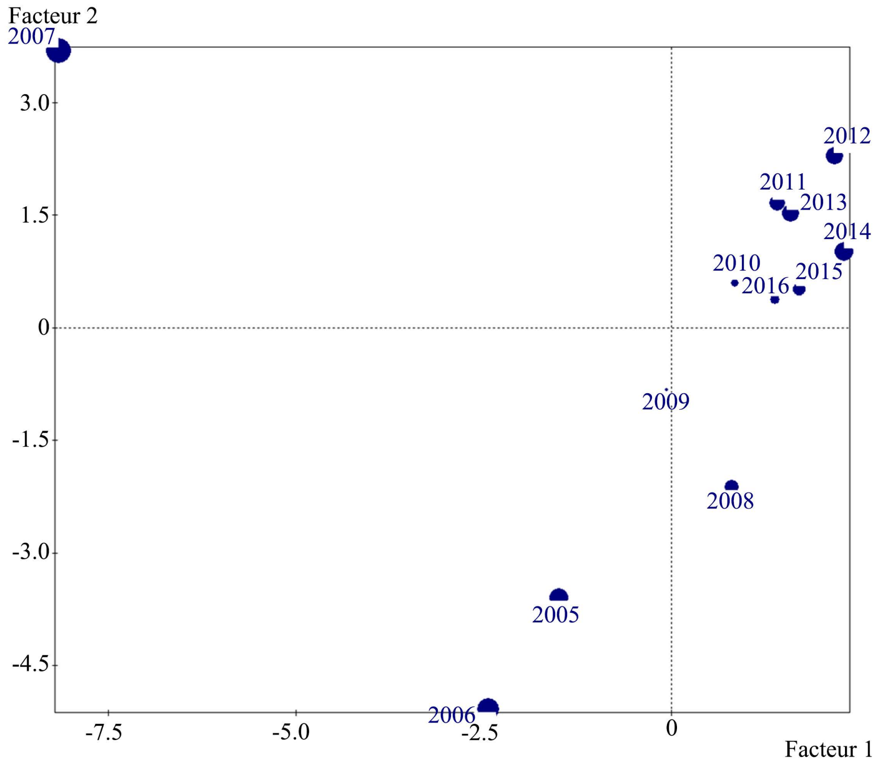

Figure 5. Observations representation on plane 1, 2.

dispersion of the observations and to distinguish the ones that are similar to each other and the ones that are distinct from each other. Also the coordinates of years in the reduced space formed by axes 1 and 2 are demonstrated in **Table 6**. Indeed, years 2012 and 2014 have the largest positive coordinates on axis 1 and years 2007 and 2006 have the largest negative coordinates on axis 1. Thus, axis 1 puts in opposition the composition of compost of years 2007 and 2006 with the composition of compost years 2012 and 2014. By linking this result with the variables results, we can conclude that the compost of years 2007 and 2006 contain high content value of Potassium, PO_4^{3-}, Lead and cadmium whereas the compost of years 2012 and 2014 contain high content value of EC, Manganese, Zinc and Chromium. By examining the original data in **Table 2**, it can be shown that the highest value of Potassium (139), PO_4^{3-} (4.46), Lead (468) and Cadmium (36.7) are detected for year 2007 whereas years 2012 and 2014 have the highest value of EC (5.31), Zinc (462) and Chromium (40).

Furthermore, years 2005 and 2006 have the largest negative coordinates on axis 2 and year 2007 have the largest positive coordinates on axis 2. Thus, axis 2 puts in opposition the composition of compost of year 2007 with the composition of compost of years 2005 and 2006. By linking this result with the variables results, we can conclude that the compost of years 2007 have high PH value and high Magnesium content whereas the compost of years 2005 and 2006 contain high organic content and high C/N ratio values. By examining the original data table, it can be shown that the high PH mean value (7.5) is detected for year 2007 whereas the compost of years 2005 and 2006 contain high organic content (57.3) and high C/N ratio values (18.5).

Table 6. Coordinates of years on plane 1, 2.

Years	Axis 1	Axis 2
2005	−1.51	**−3.60**
2006	−2.44	**−5.09**
2007	**−8.17**	**3.68**
2008	0.80	−2.12
2009	−0.06	−0.83
2010	0.84	0.59
2011	1.41	1.66
2012	2.17	2.29
2013	1.58	1.52
2014	2.30	1.01
2015	1.17	0.51
2016	1.38	0.37

In PCA, a local measure is by the squared cosine of the angle between the principal space and the vector of the point. A good representation in the projected space is hinted by high squared cosine values. Figure 5 shows the quality of the projected points represented as circle where the diameter is proportional to the squared cosine cos2. Year 2007 is well projected on the reduced plan whereas year 2009 is very badly represented so it cannot be interpreted.

3.4. Clustering Analysis

Clustering analysis is a statistical method that is used to assign observations to groups (clusters) where the observations within each cluster will be similar with respect to variables and the clusters themselves stand apart from one another. In our application, clustering analysis was used to classify the years according to the compost composition measured by the parameters cited above. Hierarchical cluster analysis and K-means were applied to form the different clusters. Firstly, a hierarchical cluster analysis method called Ward's method was used by computing the Euclidean distances as distance between years to define the number of clusters then, K-means method was applied by fixing the number of clusters to actually form the clusters. Figure 6 shows the scree diagram of ward's method values. By identifying the step where the distance coefficients plot makes a bigger jump (which is called: Step of "elbow"), the number of classes were determined. The number of clusters is obtained by subtracting the number of cases (here 11) and the Step of "elbow" (here 8), so the number of clusters is three clusters. The description of the 3-clusters partition of the years is clearly shown in Table 7.

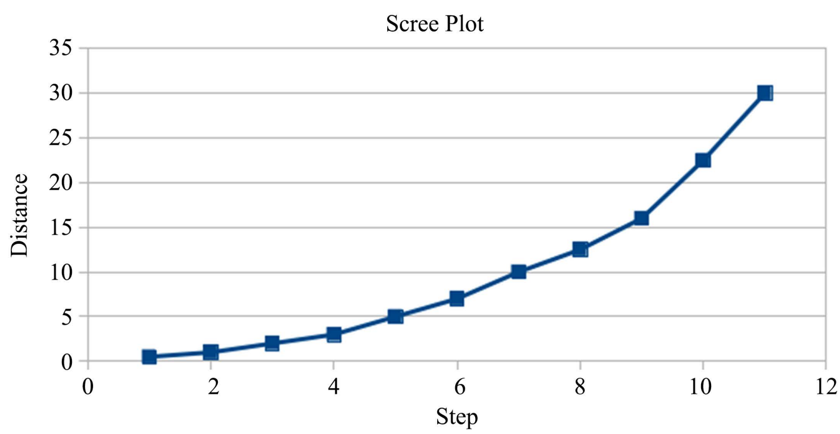

Figure 6. Scree diagram of Ward's hierarchical clustering.

Table 7. Cluster membership using K-means method.

Cluster	Years
Cluster 1	2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016
Cluster 2	2005, 2006, 2008
Cluster 3	2007

Cluster 1 contains the compost of year 2009, 2010, 2011, 2012, 2013, 2014, 2015 and 2016 whereas cluster 2 contains the compost of years 2005, 2006 and 2008 and finally, the last cluster contains year 2007.

- Cluster 1: Compost of cluster 1 year are composed with the normal content value of the studied parameters.
- Cluster 2: Compost of years 2005 and 2006 are composed with more content value of moisture, organic content, PO_4^{3-}, Calcium and C/N.
- Cluster 3: Compost of year 2007 are composed with more content value of Potassium, Lead and cadmium.

The Euclidean distances between the final cluster centers are shown in **Table 8**. Greater distances between clusters correspond to larger dissimilarities. Clusters 1 and 3 and Clusters 2, 3 are most different. Cluster 2 is somehow approximately equally similar to clusters 1.

As the country does not implement the waste sorting at source process, this leads to the variation in the composition of waste which will in its turn affect the quality of compost. Hence, compost of years 2005 and 2006 are characterized by high organic content, moisture content, phosphate, calcium and C/N. This is mainly attributed to the composition of the waste entering the composting plant which might contain high levels of organic wastes as well as agricultural crop residues leading to the increase in the aforementioned parameters which are interrelated together. As a matter of fact, a wide range of possible wastes and its by-products are available as P sources for direct recycling or for processing P fertiliser (e.g., Power et al., 2000; **Table 1**). Many of these are characterized by a high organic content suggesting the availability of P as partly organically bound and partly in other inorganic forms. Most of these sources also contain other micronutrients such as (calcium, magnesium, potassium…) which explains the rise in the levels of these parameters.

As noticed, cluster 3 representing year 2007 differs to a great extent from the other clusters as it exhibited large numbers in the contents of Potassium, PO_4^{3-}, Lead and cadmium. Those differences can be attributed to two main reasons which are:

- Technical issues pertaining to the damage of the magnetic separator in the composting plant which removes the remaining tin and metal sources that were not removed in the sorting plants. Thus, the wastes will enter the fermentation hall in the composting plant directly.
- Israeli aggression on Lebanon years 2006-2007 whereby bombs and other war debris might have led to the change in the composition of the waste as they contain heavy metals such as cadmium and chromium.

Table 8. Distance between final cluster centers.

Cluster	1	2	3
1		5.815	9.603
2	5.815		9.796
3	9.603	9.796	

As a matter of fact, our compost belongs to the type B category as it contains minimal amount of impurities such as glass which cause no harm to the crops and their usage is safe. This compost can be used as a soil amendment which can be applied on all types of agricultural commodities (fruit bearing trees, industrial crops, food and cash crops, seed crops…) and landscape commodities (ornamental seasonal and annual varieties such as seeds and transplants potting media). It is noted that sometimes no positive effect might be noticed during the first application. Better results might appear with continuous compost applications which will enrich the soil with organic material that is greatly beneficial and will render more favorable results.

Several, scientific experiments were conducted out on various agricultural productions including crops and trees whereby aspects as growth, count, uniformity, color, yield quality and quantity were closely monitored. Statistical experimental designs were conducted on farmer's land according to their cultural practices. Furthermore, concerns about the use of compost regarding the salt load and heavy metal load were addressed in experiments conducted on ornamental plants and agricultural apple and tomato production. Compost, applied as organic amendment acts mainly on improving soil permeability, aeration, tilth, water holding capacity, as well as on rendering soil nutrients more available to crop root. However, it should be properly incorporated at the proper dosages and appropriate timing. The below specifies the best fit compost dosages for application on various kinds of agricultural commodities based on the experiments conducted.

***On Trees:* (*citrus varieties, apples, olives*…)**

- For trees < than 7 years: 10 - 30 kg compost/tree;
- For trees greater than 7 years: 40 - 150 kg /tree.

***On greenhouse crop varieties:* (*Lettuce, eggplant, cucumber, radish…*)**

- Rate applied: between 2 - 5 kg/m^2.

***On on-field irrigation crops:* (*Broccoli, corn, turnip, potato, swisschard…*)**

- Rate applied: between 2 - 8 kg/m^2.

***On ornamental varieties:* (*Gerbera, verveine, marguerite, pettunia, poinsettia...*)**

Direct application:

- 25% compost: 75% peatmoss;
- 50% compost: 50% peatmoss.

It can be said that the high organic content in the MSW stream renders it ideal for composting. However, this stream contains impurities such as metals, plastics, and glass which can contaminate the final compost end product. Thus, source separating wastes prior to collection is considered as an environmentally sound and technically improved way to ameliorate the quality.

4. Conclusion

The production of municipal solid waste compost in greensite composting facility (Karantina) is considered as a unique experience of major importance in

Lebanon. Thus, the aim of this study has been to compare the composition of compost over the years based on different parameters and to detect if the final compost products are in conformity with the international standard values for specifying the modes of its usages. To achieve this purpose, representative samples were gathered and tested for an eleven-year period (2005-2016). As a result, it has been possible to conclude that the compost of year 2007 was significantly different from the other years, especially for years above 2010. Accordingly, to know the validity of the compost, confidence intervals have been applied to identify range value of each parameter and to compare it with the international standard values. In light of the obtained results, significant differences have been found in the composition of the compost over years especially for year 2007 which showed a composition different from others. Regardless of the differences, all compost samples results were in conformity with the international standards. Compost used falls under the category B compost. It was tested via experimentation and deemed successful for usage on all kinds of ornamentals, crops, and trees at adequate dosages. Over 50 percent of a developing country's municipal solid waste stream can be composted. However, to achieve a sustainable and cost effective composting, it should be incorporated within the context of an integrated solid waste management strategy.

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Conflicts of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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