Study and Assessment of Segregated Bio-waste Composting: The Case Study of Jordan

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Abstract

This research aimed to study the physical and chemical properties of compost made of different segregated bio-waste row materials. To this end, four experimental windrow piles, from different types of organic wastes (fruit, vegetable, and garden waste), were first initiated and temporally monitored. Plant residues and sawdust were used as bulking agents to ensure the required C/N ratio needed for efficient decomposition. The produced compost was monitored against moisture content, bulk density, pH, EC, total organic carbon, total organic matter, total nitrogen, total phosphorus, total potassium and C/N ratio, heavy metal concentrations and compost respiration, indicating that the biological conditions were sufficiently developed.

The monitored experimental process showed overall decreasing profiles versus composting time for moisture, organic carbon, carbon/nitrogen content (C/N) and piles volumes, as well as overall increasing profiles for electrical conductivity, total nitrogen, total phosphorus, total potassium and bulk density, which represented qualitative indications of progress in the process.

Final product quality was examined and assessed against the quality specifications of German End of Waste Criteria for bio-waste, which has been subjected to composting, aiming to specify whether the different types of organic wastes that have undergone recovery cease to be waste and can be classified as high quality compost. More specifically, on the one hand the heavy metal concentrations (Cr, Cu, Ni, Cd, Pb, Zn and Hg) were within the set limits and much lower compared to the German standards. On the other hand, compost respiration in the samples varied from 3.9 to 7.7 mgO_2/g dm, which, in turn, indicates that all the compost samples appeared to be stable and rated as class IV and V final products.

Keywords

Physical properties, Chemical properties, Bio-waste, Compost, Jordan

Acknowledgements

The research experiments, with an annual capacity of 150 m^3, were conducted on an composting pilot plant established by the United Nations Development Program (UNDP) through a Canadian grant, which is located at the Al Hussainiat landfill site around 25 km east of Al-Mafraq Governorate, Jordan. This project was carried out over six months, from August 2017. It was supported by the UNDP in terms of the provision of equipment and labor needed for the implementation of the project, as well as the provision of a mobile laboratory for in-situ measurements.

1. Introduction

Composting is a technique which can be used to reduce the amount of organic waste through recycling and the production of soil fertilizers and conditioners. Compost is primarily used as a soil conditioner and not as much as a fertilizer because it contains a high organic content (90-95%) but generally low concentrations of nitrogen, phosphorus, potassium as well as macro and micro nutrients compared to commercial fertilizers. It is comparable to peat moss in its conditioning abilities. Areas where composting can be beneficial is in the recycling of the organic fraction of the municipal waste. It reduces as much as 30% of the volume, in the form of organic matter, entering our already overcrowded landfill sites.

Furthermore the composting process, if performed correctly, transforms wet and odorous organic waste into an aesthetically, dryer, decomposed and reusable product [1].

Crop residues, unused bedding materials, silage, manures, and similar on-farm materials can be used as co-compost cover materials, along with many off-farm residues and wastes. Since a mortality compost pile cannot be turned until the bio decomposition of the carcass body has been largely completed, the type and thickness of the cover and base layer materials play a key role in influencing the biodegradation of carcasses, and the development and retention of heat that is necessary for pathogen inactivation [2].

Quality control during compost production should ensure adequate chemical and physical properties [3], as well as an adequate degree of stability and maturity [4]. The beneficial effects on crop production and soil quality reported in literature [5, 6] are directly related to the physical, chemical and biological properties of the composts [7].

The physical and chemical properties of organic wastes and the factors that affect their performance in composting require easily identifiable and reliable methods to control the process in situ, in order to make proper decisions about its performance [8].

Although the characteristics of yard waste will vary, depending upon the predominant vegetation in the area and the season of the year for its collection, composted green waste typically contains low levels of heavy metals, commonly present in sludge-based composts, which makes them more environmentally sound [9].

To produce a sound and a good quality compost, due to the lake of physical and chemical properties of the compost should be determined by the end of processing period, therefore, the main objective of this research was to study some physical and chemical properties of the first small scale application of source separated bio-waste composting in Jordan aiming to evaluate the process and compare the compost against quality standards. These properties include: moisture content, bulk density, pH, EC, total organic carbon, total organic matter, total nitrogen, total phosphorus, total potassium and C/N ratio, heavy metal concentrations and compost respiration.

2. Materials and methods

2.1 Experimental site

The research experiments, with an annual capacity of 150 m^3, were conducted on an established composting pilot plant, located at the Al Hussainiat landfill site around 25 km east of Al-Mafraq Governorate, Jordan. In this context, Jordan is home to 7.3 million inhabitants in a surface area covering of around 89,328 km^2, of which over 80% is characterized by semi-desert conditions. Over two-thirds of the growing population lives in urban centers, such as Amman, Zarqa and Irbid.

2.2 Raw materials

On the basis of the elementary value of compost as a natural fertiliser in agriculture, different types of organic wastes, such as fruit, vegetable and plant residues, were used as the composting input material. Clipping and sawdust were used as bulking agents to ensure the required C/N ratio needed for efficient decomposition.

The characteristics of initial raw materials used in composting experiments are presented in Table 1. After raw materials are prepared for composting, it should be sorted, screened and shredded if it contained large pieces, and subsequently mixed in certain ratios to maintain nutrient content and bulk porosity.

Table 1. The characteristics of initial raw materials used in composting

Properties	Fruit & Vegetable	Plants residues	Sawdust
Physical properties			
Bulk density Kg/m^3	630.00	335.00	278.00
Moisture Content MC (%)	82.00	32.00	8.00
Chemical properties			

Dry Organic Matter (%)	60.00	61.3	91.00
Total organic Carbon (%)	33.00	45.00	52.00
Total Nitrogen (%)	1.5	1.4	0.13
C:N Ratio (w/w)	22.00	32.00	400.00
pH	6.71	6.71	5.90
EC (dS/cm)	3.60	3.1	0.42
Total P (%)	0.93	1.20	0.03
Total K (%)	0.84	1.38	0.01

2.3 Methodology

Four different types of compost were obtained by mixing fruit, vegetable and plant residues at different ratios to form:

1. P1: Fruit &Vegetables (100:0)
2. P2: Fruit &Vegetables and plant residues (75:25)
3. P3: Fruit &Vegetables and plant residues (50:50)
4. P4: Fruit &Vegetables and plant residues (25:75)

During each run, the different organic raw materials (fruit, vegetable and plant residues) were blended with each other in certain ratios and gently mixed with bulking agents (tree clipping & sawdust) to ensure the required C/N ratio needed for efficient decomposition (see Table 2); then suitable conditions to support rapid aerobic composting (moisture and aeration) were supplied directly after mixing.

Table 2. Compost run ingredients and composting time

Compost Run 1	**Experiment Duration: 05.11.17 - 28.01.18**	**C/N_M***	**Run No.**
Pile 1	100% Mixed Fruit &Vegetables**	24	P1
Compost Run 2	**Experiment Duration: 05.11.17 - 28.01.18**		
Pile 1	75% Mixed Fruit &Vegetables + 25% plant residues**	25	P2
Compost Run 3	**Experiment Duration: 05.11.17 - 28.01.18**		
Pile 1	50% Mixed Fruit &Vegetables + 50% plant residues**	27	P3
Compost Run 4	**Experiment Duration: 05.11.17 - 28.01.18**		
Pile 1	25% Mixed Fruit &Vegetables + 75% plant residues**	29	P4

Note:
*** C/N_M is a theoretically calculated ratio for the resulting mixture.**
**** Mixed bio-waste means that it is mixed with 10 percent clipping and sawdust (v/v).**

The mixtures of wastes were aligned in long windrow piles (1.5 m high, 3 m width and 18 m long) by an end-front loader and turned periodically, using a specialized windrow turner, to maintain adequate O_2 levels in order to rapidly start composting. Pile moisture was controlled by adding enough water to keep the moisture content not less than 50%. This needed 84 days to produce the finished compost products. Differences in the input materials influenced the final C/N ratio of the pile. Typical operating parameters, such as, temperature, oxygen, pH, moisture content and C/N ratio, frequently monitored the composting process.

Samples were taken at the end of the composting process to determine the chemical and physical properties. Each sample was made by mixing five subsamples taken from five points in the pile. Samples were placed in polyethylene bags and transferred to the laboratory for analysis. All materials used in the composting processes were analyzed for different parameters using the International Centre of Agricultural Research in Dry Areas (ICARDA) methods for nutrient extraction procedures [10] and international standard methods for examination of water and wastewater at the NCARE laboratories and University of Rostock laboratories, Germany. Table 3 summarizes the analyzed parameters, with their corresponding standard methods.

The piles were turned periodically to maintain adequate O2 levels

Table 3. Laboratory measurement of composting parameters with their corresponding standard methods

Parameter	Method	Reference
Moisture Content (MC)	Using electronic oven by drying at (105 ^{o} C for 24 hours) (w/w).	[11]
EC	(1:10 w/v sample: water extract) by an EC meter with a glass electrode.	[12]
Ash Content	Muffle furnace by Ignition at (550 ^{o} C for 6 hours).	[12]
Total Organic Carbon (TOC)	TOC (%) = ((100 - Ash %) ÷1/8)	[13]
C/N Ratio	Expressed as ratio of (TOC / TKN) %	
Total kjeldahl-N (TKN)	Regular Kjeldahl Method (automatic analyzer)	[12]
Total P and K	Atomic absorption spectrometric methods	[11]
Respiration Activities (AT4)	Soil quality-laboratory methods for determination of microbial soil respiration (ISO 16072:2002)	[14]
Heavy Metals	Inductively Coupled Plasma-Mass Spectrometer, Thermo-Elemental ICP-MS-X Series	[15]

The method of composting, which was based on the principle of windrow technology, was carried out by means of turning that allowed the aerobic decomposition of organic waste into odour free and stable compost. Therefore, the prepared materials were well-blended and aligned in long windrows piles, in dimensions of 18m long, 3m width and 1.5m height, to ensure efficient mechanical turning. Most types of bio-waste are a good source of nitrogen but they may be low in carbon, depending on the amount of bedding used. Most materials available for composting do not fit the ideal ratio, so different materials must be blended. Proper blending of carbon and nitrogen helps to ensure that the composting temperatures will be high enough for the process to work efficiently and ensures that adequate supplies of other nutrients are available for microbes.

During the four composting runs, four windrow piles from different organic wastes were aerobically composted using the windrow system in an open site area. Each compost run consisted of one pile. The raw materials were mixed in different component ratios (weight basis) depending on theoretical calculations to adjust the initial C/N ratios between 25 and 30, as recommended for rapid aerobic composting.

The initial C/N ratios were theoretically calculated according to the following formula [16]:

$$\mathbf{C/N_M = \frac{\Sigma\,(C/N_{1\ldots n} \times t_{1\ldots n})}{\Sigma\, t_{1\ldots n}}}$$

where,

C/N_M : C/N ratio of resulting mixture.

$C/N_{1\ldots n}$: C/N ratio of individual components of the mixture, (from 1 to n).

$t_{1...n}$: mass of individual components of the mixture in tons (from 1 to n).

The composting system, which was adopted in this pilot plant, was based on the principles of windrow technology. The composting piles were turned mechanically using a special compost turner (MENART 4719 SPM turning machine, Belgium), according to a turning schedule as follows: 1) 3-4 turnings in 1st week, 2) 2-3 turnings in 2nd week, 3) 2 turnings in 3rd week, 4) one turning per week in the 4th and 5th weeks, and, from the 6th week onwards, one turning every 2 weeks if heating still occurred.

Water was continuously added to the piles to achieve the required moisture content of 50 – 60% (wet basis). The temperature was expected to increase due to the microbial activity and it should be noticeable within a few hours of forming a pile, as easily degradable compounds will be consumed. The temperature can be measured with a digital probe of one meter (three feet) long.

It was expected that the composting process would finish 8 weeks from the first turning. However, the compost remained in the pile for 4 additional weeks for the purpose of curing, so that each pile required a total of 12 weeks to accomplish complete composting. However, to eliminate the prolongation of the research project time, the four runs were carried out at the same time interval.

During the implementation of composting runs, a continual monitoring program was carried out on a daily basis and permanent control of the pile was maintained. This program contained direct in-situ measurement for the operating parameters of the composting process, such as temperature, pH, oxygen and carbon dioxide percentage (v/v) inside windrow piles. These parameters helped to schedule the turning frequency of the piles.

For data interpretation during the composting process, regular sampling was carried out during the different stages of composting. In-situ measurements, which were complied with the parameters to ensure a proper composting process and to indicate the composting maturity, are tabulated in Table 4. The table also shows the frequency of parameter analysis. The ambient temperature and temperature within each pile were measured daily. The pile's temperature was measured by dividing the pile into five equal sections and taking temperature readings at five locations for each section (at the pile bottom, 0.25cm from the bottom, in the middle, 0.25cm from the top, and at the pile surface), then the average readings were taken.

CO_2 and O_2 percentages inside each pile were measured directly using digital meters (Models 115 and 117 Testoryt Compost Systems) and before each turning operation (twice reading per each pile). The pH values were measured using a pH meter with glass electrode (1:10 w/v compost: water extract).

Table 4. In-situ measurements of operating parameters during the composting process

Test	**Method**	**Frequency**
Temperature	Using a digital dry bulb thermometer (Compost Systems)	Daily
O_2 (v/v)	Using Oxygen meter (Testoryt O_2 Compost Systems, Model 117)	Once a week
CO_2 (v/v)	Using Carbon Dioxide meter (Testoryt CO_2 Compost Systems, Model 115)	Once a week
pH	(1:10 w/v sample: water extract) by a pH meter (GPRT 1400) with a glass electrode Redox-Electrode GE 105	Once a week

Representative samples were collected by dividing the pile into five equal sections and taking samples at three locations in a pile (0.25cm from bottom, in the middle, and 0.25cm from the top). The collected samples were analysed at NCARE laboratories for the following parameters: moisture content (oven drying 105^{o}C for 24hr), ash content (expressed as percentage of residues after muffle furnace ignition at 550^{o}C for 6hr), and Total Kjeldahl Nitrogen (TKN) using the regular Kjeldahl Method by FOSS Kjeltec™ 2300 Analyser Unit. Due to the lack of potential at NCARE laboratories to analyse the stability analysis (AT4) and heavy metal concentrations of the samples, the collected samples were sent to Rostock University laboratories, Germany, for analysis. The frequency of the parameters analysis is listed in Table 5.

Table 5. Frequency of composting parameters analysis in the laboratory

Laboratory Test	**Frequency**
Moisture Content (MC)	Once a week
EC	Every two weeks
Ash Content	Every two weeks
Total Organic Carbon (TOC)	Every two weeks
C/N Ratio	Every two weeks
Total Kjeldahl Nitrogen (TKN)	Every two weeks
Total P and K	Start and end
Total organic matter	At the end
AT4	At the end
Heavy Metals	At the end

The total organic carbon was estimated from the ash content, according to the formula of [13] as:

$$\mathbf{TOC\ (\%)} = \frac{\mathbf{VS\ (\%)}}{\mathbf{1.8}} = \frac{\mathbf{100 - Ash(\%)}}{\mathbf{1.8}}$$

Where,

TOC (%): percentage of total organic carbon.

VS (%): percentage of volatile solids.

Ash (%): percentage of ash content.

The C/N ratio was calculated using the following formula:

$$\frac{\mathbf{C}}{\mathbf{N}} = \frac{\mathbf{Carbon\ Content\ \%}}{\mathbf{Nitrogen\ Content\ \%}} = \frac{\mathbf{TOC\ (\%)}}{\mathbf{TKN\ (\%)}}$$

Total phosphorus (P) was measured calorimetrically [17] and Total potassium (K) was by flame photometry [12]. For the purpose of evaluating the stability of the composted final product and determining the optimum C/N ratio, a compost respiration index (biological activity) was estimated using soil quality-laboratory methods for determination of microbial soil respiration (ISO 16072:2002) [14]. AT4 analysis and heavy metals concentrations were analysed at Rostock University Laboratories, Germany.

3. Results and discussion

This section shows the experimental data, which were collected during composting experiments. All tables and figures in this chapter were constructed from these results. The experiments were carried out during four runs, which contained four compost mixtures. The parameters of temperature, moisture content, pH, oxygen, carbon dioxide, C/N ratio, volume reduction, bulk density, nutrient content and water consumption were controlled and monitored during composting. The main operating parameters, which were controlled and monitored directly during composting, are discussed in the following sections.

3.1 Characteristics of the raw materials

As previously mentioned, four compost runs consisted of three mixtures, P1, P2, P3 and P4. P1 was formed from four portions of fruit &vegetables (4F&V: 0 plant residues), P2 from three portions of fruit &vegetables and one portion of plant residues (3F&V: 1 plant residues), P3 from one portions of fruit &vegetables and one portion of plant residues (1F&V: 1 plant residues), P4 from one portions of fruit &vegetables and three portion of plant residues (1F&V: 3 plant residues).

It is widely known that three components are required for building a compost mixture, including the primary substrate, amendment, and bulking agents [18]. In this study, fruit &vegetables and plant residues were considered as the primary substrate. Sawdust was mainly considered as an amendment to balance the C/N ratio or to modify the pH value, where fresh bio-waste was mixed with approximately 10% sawdust. Clippings or branches and woodchips were used as bulking agents to provide structure and porosity for the compost piles.

The mixing ratios were theoretically calculated based on the formula of Amlinger et al. (2005) to achieve a C/N ratio that ranges from 25 to 30 for mixtures depending on the weight basis [16]. After that the windrow piles were mechanically turned, according to a periodic schedule, to maintain effective aerobic decomposition. Water was added to provide optimum moisture, which is critical to microorganism function during the composting process. The moisture content for prepared piles was adjusted to range from 50-60% (w/w). Monitoring of temperature, moisture content, and oxygen supply was carried out to ensure an effective composting process.

The blended ratios for the compost mixtures were listed in Table 1, and the initial physical and chemical characteristics of the composting piles raw materials are listed in Table 6. The composting process was carried out at ambient conditions in an open site and the windrow piles needed 12 weeks to achieve biologically stabilised and heat sterilised compost.

Table 6. The initial physical and chemical characteristics of composting piles

Parameter	P1	P2	P3	P4
Ash Content (%)	56.1	64.4	57.2	55.1
Volatile Solids (%)	43.9	35.6	42.8	44.9
TOC (%)	25.4	27.4	30.0	33.3
TKN (%)	1.06	1.09	1.11	1.15
C/N Ratio (w/w)	24.0	25.1	27.0	29.0
Moisture Content MC (%)	28.0	26.0	25.0	23.0
pH	6.84	7.36	7.71	7.97
EC (dS/m)	2.43	2.45	3.01	3.36
Total P (%)	1.12	1.27	1.44	1.48
Total K (%)	1.29	1.37	1.41	1.47
Initial Pile Volume m^3	36.0	38.0	36.0	40.0
Initial Bulk Density Kg/m^3	521.0	472.0	371.0	295.0

3.2 Physical properties

3.3 Temperature monitoring

An increase in the temperature was clearly observed during the early phase of composting for all piles (see Figure 1). An internal temperature profile, characterized by an initial increase followed by a decrease finally approaching ambient temperature, which can be traced back to the typical rise and fall change in temperature with the time expected in the traditional windrow composting.

According to the figure, all piles demonstrated a typical composting temperature trend, achieving thermophilic temperatures of more than 55°C, and reaching approximately 67°C within two weeks, especially in pile P2 (thermophilic phase). Thereafter, the temperature declined slightly to around 60°C, and remained above 50°C from week 6 to week 8 (active phase), before dropping further during the second phase of composting (curing phase).

The addition of a bulking agent allowed for good aeration during composting, favouring microbial respiration and augmenting the exothermic activity of the decomposition process. As reported by Smith and Jasim (2009), the ideal thermophilic temperatures during the composting process at a small scale are sometimes difficult to be reached if only vegetable residues are composted [19].

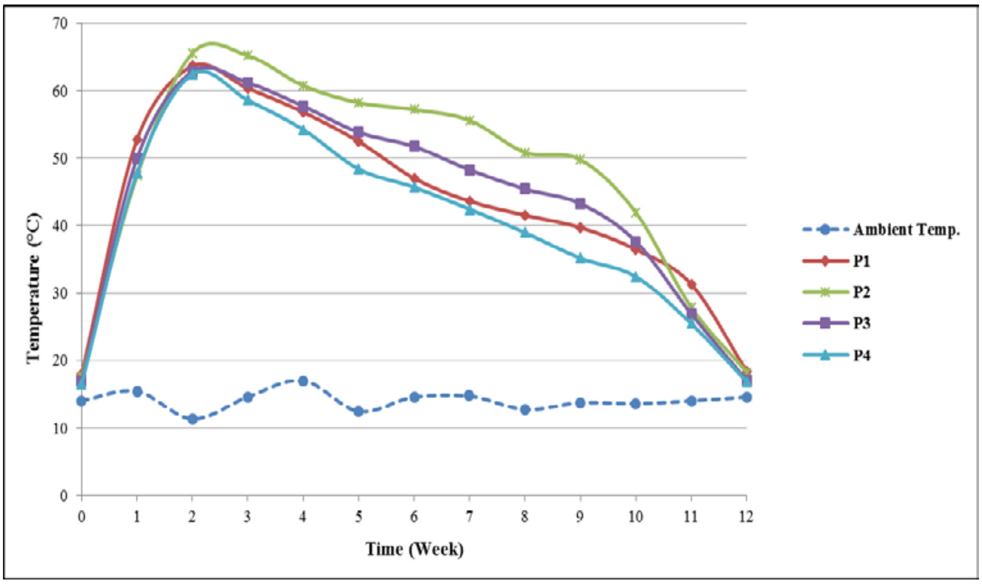

Fig. 1. Average temperature profiles during composting runs

As the process was progressing, the temperature started to decrease gradually after five weeks and, with the ambient temperature, reached a constant level after 12 weeks. Relatively, in P4, the short thermophilic development and continual temperature decrease indicated high initial C/N ratios (low nitrogen content), which inhabits the carbonaceous degradation of raw compost material [10, 20].

In windrow composting, windrow size, turning frequency, initial C/N ratio, ambient temperature, moisture content and oxygen supply are among the variables that can affect the temperature [21]. The thermophilic period for all piles was achieved according to USEPA guidelines for pathogen control during the active process [22].

As the organic matter became more stabilised, the microbial activities and decomposition rate declined, and thus the temperature gradually decreased to the ambient level, marking the end of the active phase. The reduction of pile temperature to the ambient temperature was clearly evident in the last four weeks, indicating that the maturation process of organic materials into biologically stabilised products was efficiently accomplished.

3.4 Oxygen and carbon dioxide concentrations

Under aerobic conditions, emissions of carbon dioxide were proposed as a good indicator for the amount of degraded organic carbon. Thereby, the key factor of the composting process (i.e., aerobic biological activity) would be monitored and optimized through the continuous measure of oxygen levels. If the oxygen supply is limited, microorganisms favour anaerobic conditions that cause high odour potential [23]. The concentration of O_2 and CO_2 was considered as an indicator for turning the piles, regardless of the turning schedule previously discussed in the research methodology. If the O_2 concentration was found to be nearing zero in any sampling location, turning was immediately applied to provide the microorganisms in the pile with the required oxygen.

As is clearly seen in Figure 2. the initial concentration of oxygen within the body of the piles was very low, due to the high rate of biological activities. This can be also seen and proven from the results of CO_2 concentrations in the initial phases, in which the concentrations were very high. As the composting process progressed, the oxygen concentration increased and CO_2 concentrations decreased accordingly. This is attributed to the decreasing rate of biological degradation [24].

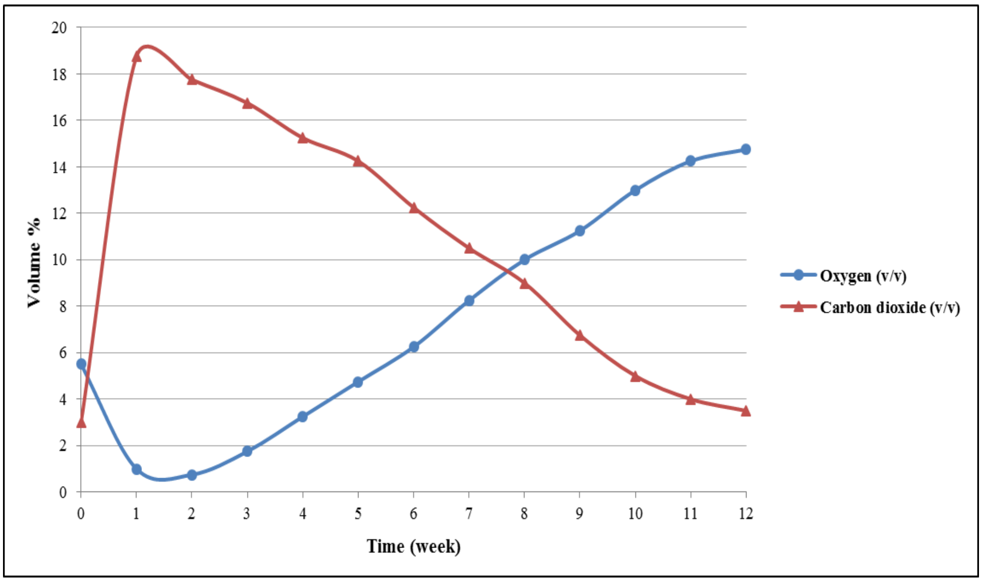

Fig. 2. Average O_2 and CO_2 concentrations for all piles during the composting runs

As evident in Figure 2, CO_2 concentrations inside the entire piles immediately increased to around 20% (v/v) during the first week of composting. O_2 concentrations followed an opposite trend during the composting time, declining rapidly to the lowest level (0%) from the start of composting. Thereafter, O_2 concentrations gradually increased as the composting process progressed, reaching the highest levels during the curing phase. The change in trends of O_2 and CO_2 concentrations is attributable to vigorous microbial activity in the aerobic composting. Therefore, concentrations of O_2 and CO_2 in an aerobic process function as a monitoring index for the provision of sufficient oxygen to the piles via windrow turning practices. Bulky materials, such as woodchips, are often used to maintain structure and porosity, because they decompose at a much slower than other types of carbon sources, such as sawdust. Furthermore, the plant residues used in P2, P3 and P4 had a better structure than the fruit & vegetable (P1), which was critical in providing porosity and, hence, aeration. Well-aerated mixtures resulted in a low turning frequencies and high quality products [25]. The concentration of CO_2 in the final curing phase of composting (about 3%) clearly demonstrates that existing biological degradation proceeds at a very low rate.

3.5 Moisture content monitoring

Moisture content levels inside the composting piles were remained close to 50 % to ensure high organic matter degradation with enough porosity and proper aeration and, thus, aerobic degradation and composting throughout the entire experimentation. Water was added to maintain the moisture levels at around 50% for the first 8 weeks to maintain optimum microbial activity with enough oxygen supply. In general, the moisture content decreased gradually during composting, causing slow decomposition and low temperatures. The moisture content values ranged from 23 to 28% for different compost types (see Figure 3). The lowest value of moisture content (23%) was found for fruit/ vegetables with plant residues

(1:0) compost and the highest value of moisture content (28%) was obtained for fruit /vegetables with plant residues (1:3) compost.

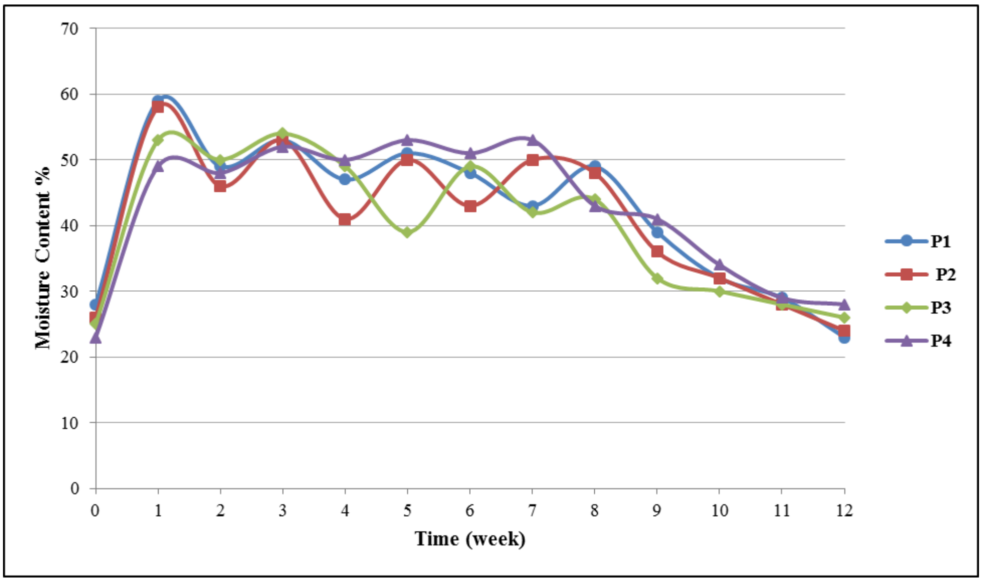

Fig. 3. Average moisture content during composting runs

Large variations in the moisture content during the active composting phase, especially between week 2 and week 8, are attributed to the thermophilic temperatures, due to vigorous microbial activity, as well as the excessive turning frequency, which reduced the existing moisture content inside the piles in relative amounts. Moreover, a higher porosity and aeration entailed a greater sensibility in the variation of moisture. When the moisture of the compost decreased, limiting the process, also the temperature decreased, which was all the more evident in the treatment with the high bulking agent ratio (P3 & P4) where the highest decrease of temperature was observed; likewise, P3 & P4 increased the temperature quickly when enough moisture was provided by watering again.

As the curing phase started at the end of week 8, the moisture content in all entire piles gradually decreased to around 25%, especially in P3. The higher water content, by the end of composting, was in P4, which was found to be around 30%, which was attributed to the high initial C/N ratios (high carbon content) within raw materials used, which reduced the decomposition rate and become more slowly [26].

3.6 Bulk density, piles volume and water consumption

The reduction ratio of the bulk volume was significantly influenced by the composting time, decomposition rate, turning frequency and bulking materials used that give support for the pile structure [27]. As a result of the biological activity, organics in the composting material (substrate) were mineralized and transformed into stable materials and carbon dioxide [28]. Accordingly, this resulted in a reduction in the volume of the composting material. The pile volumes decreased in the range of 22-30% by the end of the composting processes (after 12 weeks), which was attributed to vigorous microbial activity within the pile (see Figure 4). This is considered crucial to further justification for composting, resulting in a 30% reduction in transportation requirements for composted material, in comparison to uncomposted, unstabilised organic material.

The results indicate that the bulk density value ranged from 440 to 603 kg m^{-3} for different compost types. The highest value of bulk density (603 kg m^{-3}) was found for P1, which was formed from one portions fruit and vegetable and zero portion of plant residues compost (1F&V: 0P) and the lowest value of bulk density (440 kg m^{-3}) was found for P4, which was formed from one portions fruit and vegetable and three portion of plant residues compost (1F&V: 3P). Hurerta-Pujol et al. (2010) found that the bulk density values were between 447 and 502 kg m^{-3} for different compost types, as agreed with [29-32] results.

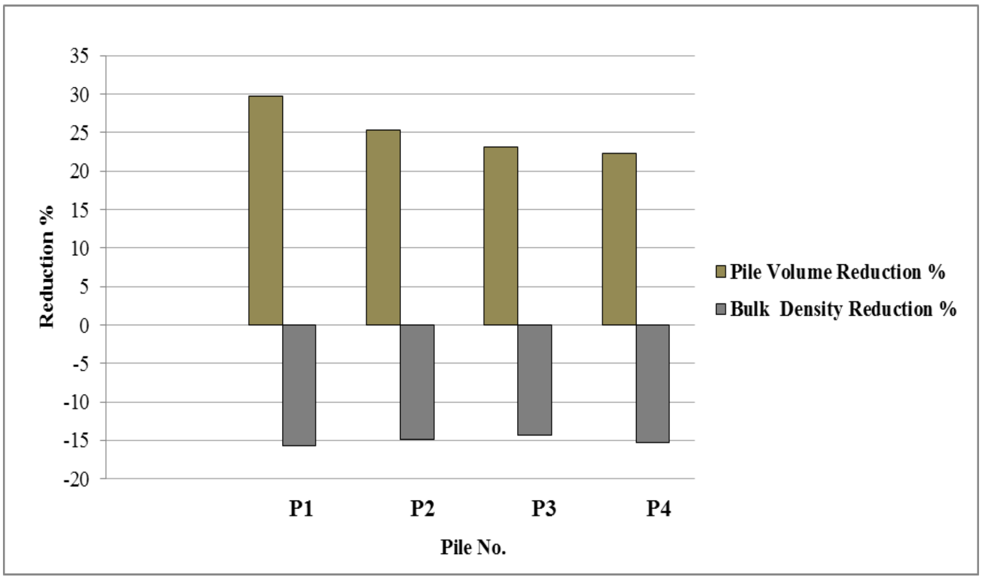

Fig. 4. Pile volume and bulk density during composting runs

This reduction in the material volume is offset by an increase in the bulk density, where an approximate 15% increase was achieved. This can be attributed to the fact that the bulk density of compost increases with decreasing the compost's total organic matter (see Figure 5). It could be seen that the bulk density of compost decreases with increasing the compost total organic matter. It increases from 340 to 603 kg m^{-3} when the total organic matter decreased from 39.7 to 24.3%.

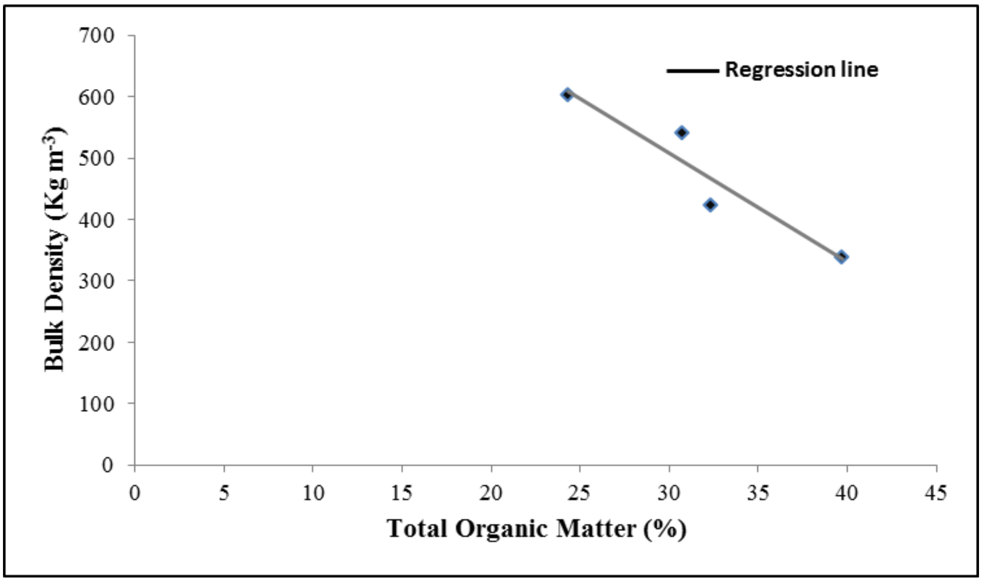

Fig. 5. The relationship between the bulk density and the total organic matter

The regression between the bulk density of compost and the compost total organic matter is show the following equation:

$$BD = -17.694\ TOM + 1039 \qquad R^2 = 0.90$$

Where:

BD is the bulk density (kg m^{-3})

TOM is the total organic matter (%)

The internal heat generated due to microbial activities and the ambient environment affected water for the provision of optimum moisture levels inside the composting piles. The summary of the initial organic material volume, final composting volume, and water added volume is shown in Figure 6. It is can be seen that the amount of added water (in volume) was more or less equal to the amount of organic fertilizer produced (in volume), so that a 1:1 ratio can be assumed. In other words, the ratio of water added in relation to the amount of raw composting material was about 60% for the four piles.

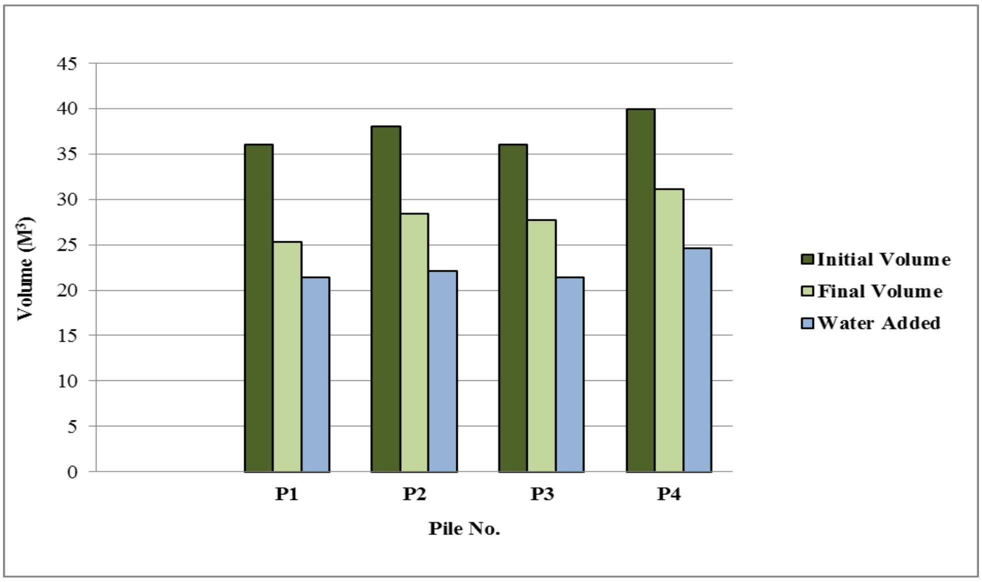

Fig. 6. Pile water consumption during composting runs

3.7 Chemical properties

3.8 C/N ratio monitoring

The C/N ratio plays an important role in the nutrient balance in a composting mixture, indicating the amount of carbon available, in relation to nitrogen, for the composting microorganisms.

The results of C/N ratios obtained during composting at different time intervals are shown in Figure 7. As seen in the graph, the four piles had different starting C/N ratios. It can be clearly observed that the initial C/N ratios were in the range of 24 to 29 in all the piles. They all showed similar C/N ratio reduction profiles and trends. However, Figure 7 shows that C/N measures of the respective experimental composting windrow piles more or less clearly decreased overall versus the weekly composting time, which is qualitatively consistent with the C/N reduction generally expected in the evolution of the composting process [10]. The C/N ratio clearly decreased in the second phase of composting (after 8 weeks), in comparison to the first phase (up to 8 weeks) of composting. This, however, is expected as a result of the lower degradation rate in the second phase.

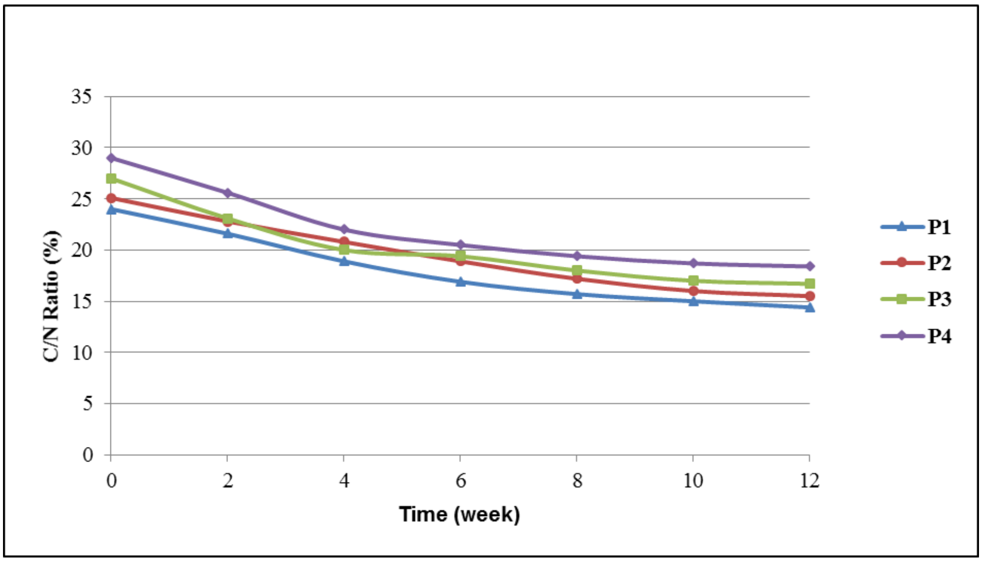

Fig. 7. Average C/N ratio profiles during composting runs

The final C/N ratio ranged from 14.4:1 to 18: 4 for all the piles. The lowest value of C/N ratio (14.4: 1) was found for P1 and the highest value of C/N ratio (18.4: 1) was found for P4. These results are in agreement with the results obtained by Dougherty (1999), who found that the C/N ratio ranged from 15:1 to 20:1, which is ideal for ready-to-use compost [33, 34].

Regarding the reduction of C/N ratio, it is clearly seen that the highest reduction of C/N ratio took place in the P1 pile, where more than a 40% reduction was achieved (see Figure 8). This high level of reduction can be attributed to the degradation process, as well as to the low starting C/N ratio [10]. Furthermore, pile P2, P3 and P4 exhibited a C/N ratio reduction of about 39, 38 and 36%, respectively.

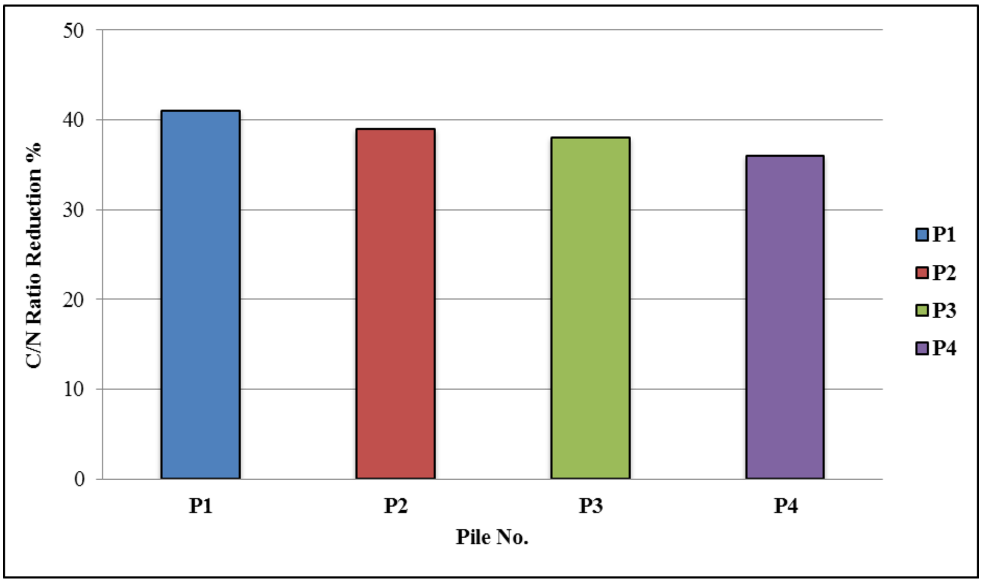

Fig. 8. C/N ratio reduction profiles during composting runs

Regarding the total organic carbon results it was found that it ranged from 26.9 to 47.9% for different compost types under study, where, the lowest value of total organic carbon (26.9%) was found for P1, which was formed from one portions fruit and vegetable and zero portion of plant residues compost (1F&V: 0P) and the highest value of total organic carbon (47.9%) was obtained for P4, which was formed from one portions fruit and vegetable and three portion of plant residues compost (1F&V: 3P). These results are in agreement with [35] who found that the optimum value of total organic matter higher than 10%.

For total nitrogen, the experimental composting windrow piles exhibited more or less pronounced overall increases in measured contents versus weekly composting time. This increasing nitrogen condition appears to be in agreement with the concentration effect that is generally expected in the composting process due the gradual decomposition of organic matter, which causes a weight loss and, consequently, a relative increase in concentration (in terms of dry matter) provided that a possible concurrent nitrogen loss is relatively less than the weight loss [33]. However, as decomposition proceeded, the nitrogen content of the piles generally increased. The total nitrogen values ranged from 1.87 to 2.61% for different compost types under study. The lowest value of total nitrogen (1.87%) was found for for P1, which was formed from one portions fruit and vegetable and zero portion of plant residues compost (1F&V: 0P) and the highest value of total nitrogen (2.61%) was found for for P4, which was formed from one portions fruit and vegetable and three portion of plant residues compost (1F&V: 3P). These results are in agreement with those obtained by [9] who's found that the total nitrogen rate ranged from 0.99 to 3.01%. Accordingly, the carbon ash content was slightly decreased due to high microbial activity during composting, where large amounts of carbon were transformed via microbial respiration to CO_2 [33].

3.9 pH monitoring

The pH value of the compost is important, since applying compost to the soil can alter the soil pH, which, in turn, can affect the availability of nutrients to the plant [36, 37]. The pH is a measure of the active acidity in the feedstock or compost and most finished composts will have pH values in the range of 6 to 8; these ranges can be substantially different depending on the kinds of feedstock used. Microorganism growth and gaseous loss of ammonia are influenced by pH variations during composting, therefore, the optimum pH for microbes involved in decomposition lies between 6.5 and 7.5 [10].

After a possible initial drop that most likely occurred during the first two weeks of composting [36], the pH evolutions presented in Figure 9 appear to be in qualitative agreement with the typically expected pH-time profile of the composting process [36]. In particular, the experimental windrow piles showed a similar temporal sequence with a phase of increasing pH followed by a decreasing phase (although with a final increased value in the sixth week).

The pH profiles of the pile materials during the four runs are shown in Figure 9. It is clearly seen that there was a pH decrease during the first two weeks of composting, where the pH of decomposition was between 6 and 7.5. The decrease in the pH values is attributed to the biological activities of the aerobic decomposition, where the hydrogen atom (acid) was produced [38].

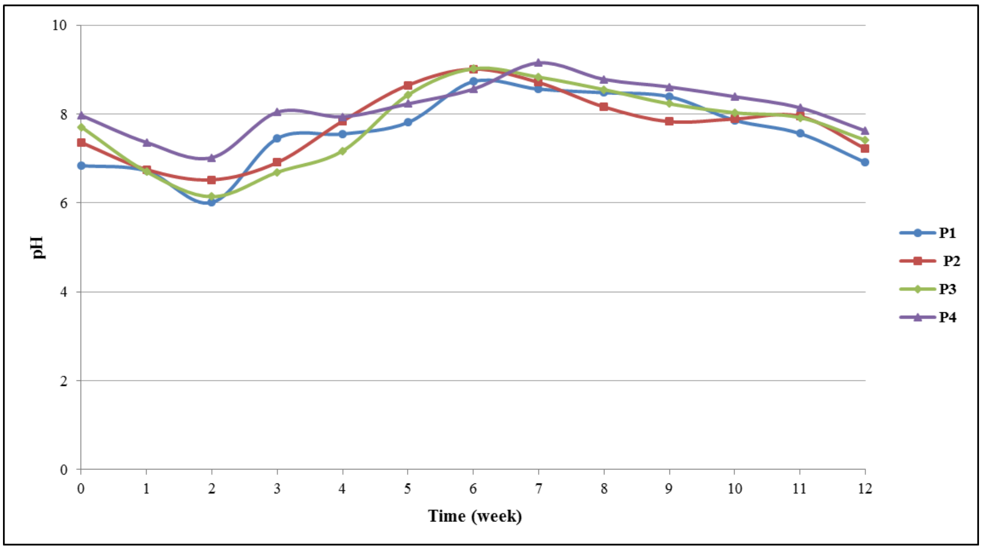

Fig. 9. Average pH profiles during composting runs

In spite of the high rate of biological activity during the initial phase of composting, pH values were no less than 6. This can be explained by the high buffering capacity of the composting material, which averts a sharp decrease in the pH values [25]. As composting process is progressing, pH values increased up to 9, and had generally stabilized between 6.9 and 7.6 by the end of the second composting phase. This pH range is in the optimum range for growing media as mentioned by [39] who stated that the optimal range is from 5.2 to 7.5.

3.10 Electric Conductivity (EC) monitoring

Electric conductivity is a measure of the combined amount of salts in the compost: the greater the concentration of soluble salts in the compost, the greater the electrical conductance. Generally, compost soluble salt levels typically range from 1-10ms/cm [40].

As shown in the diagram below (Figure 10), the measures of electrical conductivity in the experimental composters increased overall versus the weekly composting time. In general, the increase in electrical conductivity, which parametrically reflects the salinity of the matrix, is an additional indication of progress in the composting process as the gradual decomposition of organic matter is usually accompanied by the increased relative concentration of different mineral ions [41].

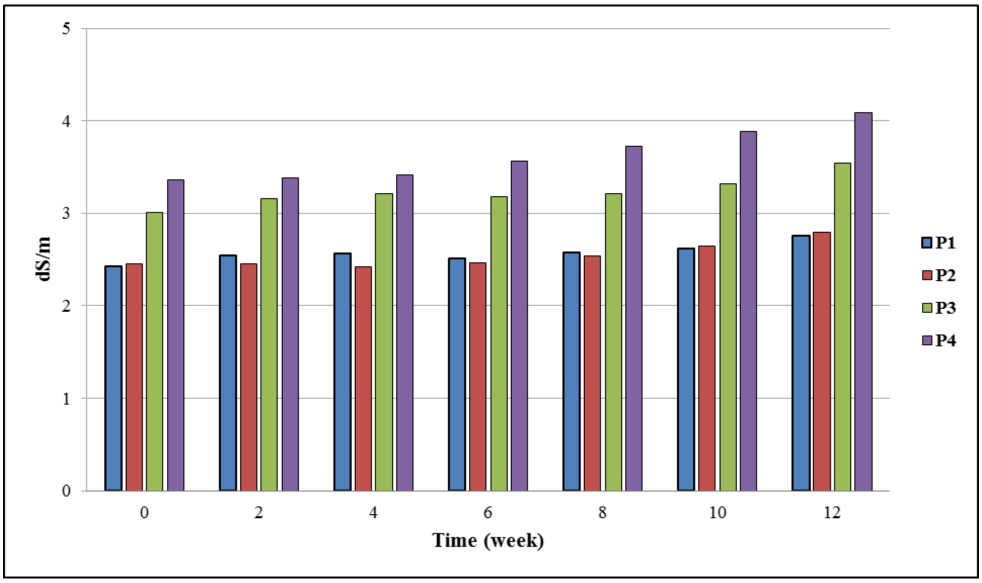

Fig. 10. Average EC values during composting runs

The electric conductivity (EC) of the compost samples varied from 2.76-4.1 dS/m, with a median value of 3.17. This EC range is in the optimum range (2.0 to 4.0) for growing media as mentioned by [41]. Compared to the initial values, the final EC for the composting product for all runs showed an increase of 11.9, 12.5, 14.9 and 17.8% in P1, P2, P3 and P4, respectively. This can be attributed to the mineralization in the organic material of the waste and to the EC content of added water.

3.11 Nutrient content

Organic wastes supply balanced nutrients to plant roots, stimulate growth, increase the organic matter content of the soil, including the 'humic substances' that affect nutrient accumulation, and promote root growth. In fact, they improve the total physical and chemical properties of the soil [42]. They also add useful microorganisms and provide food for the existing soil microorganisms, thus increasing their biological properties and capacity for soil fertility self-renewal. One ton of compost may contain 10lbs of nitrogen (N), 5lbs of phosphorus (P_2O_5), and 10lbs of potash (K_2O) [43].

With regard to extractable nitrogen, phosphorus and potassium, the temporal evolutions in the experimental windrow piles are reported in Figure 11, which shows all of the experimental windrow piles exhibited overall increases in measured N, P_2O_5 and K_2O contents versus weekly composting time, with final values (by the end often weeks) of 1.87, 2.1, 2.33 and 2.61% for N concentrations; 1.65, 1.85, 2.09 and 2.21% for P concentrations; and 1.69, 1.77, 1.85 and 1.98% for K concentrations, which were exhibited in P1, P2, P3 and P4, respectively.

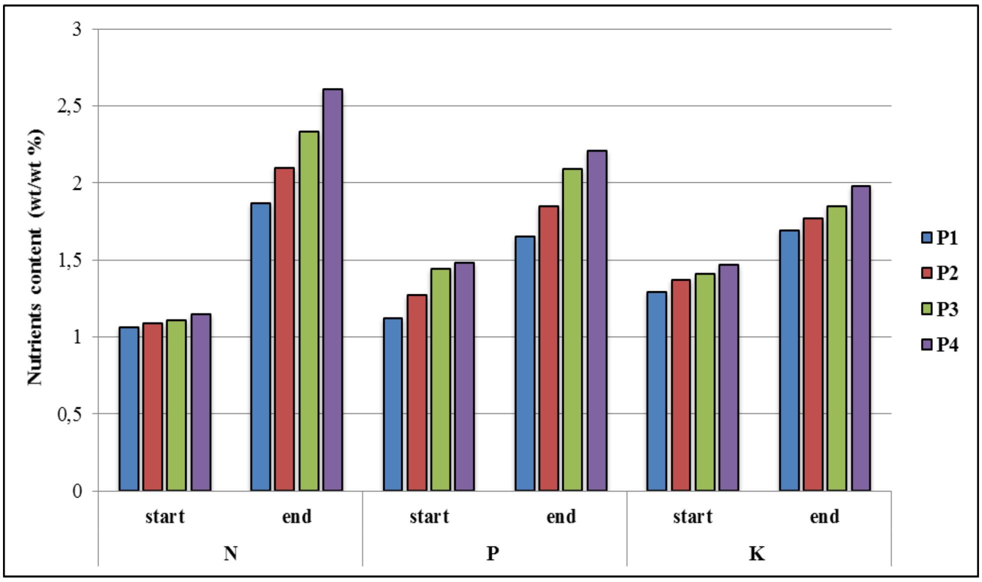

Fig. 11. Nutrient content wt/wt (%) during composting runs

It can be clearly seen in our study, as illustrated in Figure 11, which shows an increase in the agricultural beneficial fertilizing elements of nitrogen, phosphorous and potassium. A 43, 48, 52 and 56% increase in N concentrations; 32, 31, 31 & 33% increase in P concentrations and 24, 23, 24 & 26% increase in K concentrations, were exhibited in P1, P2, P3 and P4, respectively. This increase was due to the reduction in composting volume and the increase the in pile bulk density [42, 43].

3.12 Heavy metals

High levels of heavy metals represent an obvious concern when the compost is to be applied to food crops [44, 45]. Heavy metals do not degrade during the composting process and always become more concentrated due to the microbial degradation. Heavy metals in compost products are sourced from the raw materials, which have been subjected to composting. Thus, the method of waste collection (i.e., source-separated or mixed collection) and composition characteristics of the raw materials significantly affect the quality of the compost product [46]. With regard to heavy metals concentrations, the analysed samples showed that the resulting contents in the four windrow piles monitored in the twelve weeks of composting were below the respective upper limits of Table 7.

Table 7. Heavy metal concentrations of compost compared with German standards [47]

Parameter	Range	German standard (BioAfV)	
		Class A	Class B
Pb mg/kg	0.9 – 2.40	**150**	**100**
Cd mg/kg	0.19– 0.39	**1.5**	**1.0**
Cr mg/kg	12 – 17	**100**	**70**
Cu mg/kg	11 – 15	**100**	**70**
Ni mg/kg	11 - 14	**50**	**35**
Hg mg/kg	< 0,05	**1.0**	**0.7**
Zn mg/kg	52 – 68	**400**	**300**

Source separation is generally regarded as the most effective and promising method for improving compost quality in terms of metal content [48]. The content of the metals (Pb, Cd, Cr, Cu, Ni, Hg & Zn,) in source-separated compost is shown in Table 7, which clearly indicate the effectiveness of source-separated collection on metal content control, where the concentrations of all seven heavy metals were significantly lower in the source-separated compost.

3.13 Organic matter

Four samples (one sample from each run) were tested in n=3. Organic matter (OM) in the samples varied from 19% to 40% (see Figure 12). All of the compost samples had organic matter content lower than the value set by the German standard (BioAbfV), which should be between 15-45% [47].

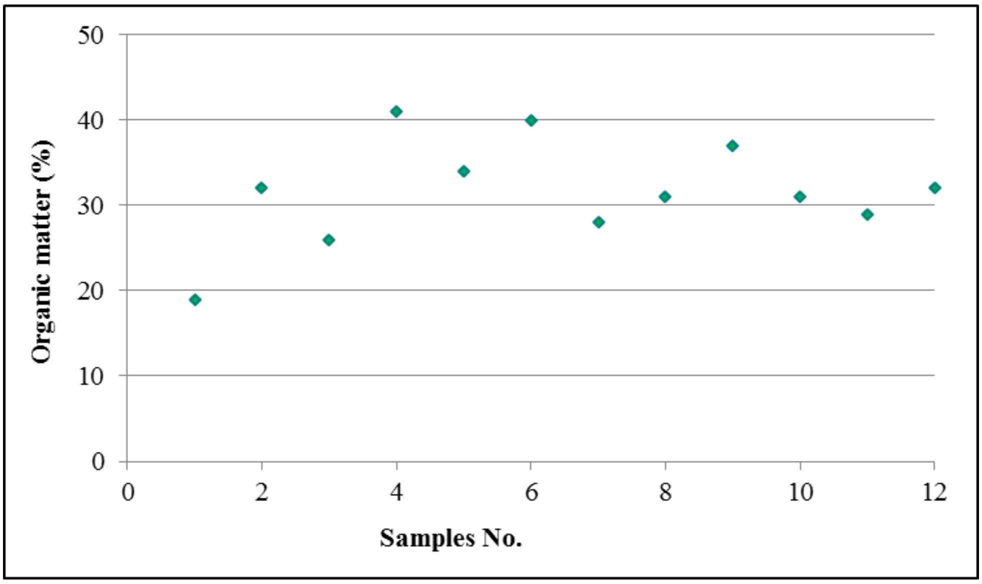

Fig. 12. The results of the organic matter content in the analyzed compost samples

The results are averages, with the lowest average value of total organic matter (24.3%) was found for P1, which was formed from one portion of fruit and vegetable waste and zero portion of plant residues compost (1F&V: 0P). The highest average value of total organic matter (40%) was found for P4, from one portions fruit and vegetable waste and three portion of plant residues compost (1F&V: 3P). These results are in agreement with Benito et al., (2005) who found the highest value of total organic matter to be about 44% [9].

3.14 Respiration activities

Respiration is directly related to the metabolic activity of a microbial population. Microorganisms respire at higher rates in the presence of large amounts of bioavailable organic matter, while the respiration rate is slower if this type of material is scarce. In the composting process, respiration activity has become an important parameter for the determination of the stability of the compost. It is also used for the monitoring of the composting process and is considered to be an important factor for the estimation of the maturity of the material [49].

A wide range of respirometric protocols has been reported in the literature, based either on CO_2 production, O_2 uptake or release of heat. The most common methods are those based on O_2 uptake. Respirometric assays are affected by a number of parameters including temperature, humidity, and both incubation and pre-incubation conditions. In the European legislation drafts (European Commission 2001), stabilisation means the reduction of the decomposition properties of bio-waste to such an extent that offensive odours are minimised and that respiration activity after four days is below 10mg O_2/gm dm [50-52]. The high value of Maturity Index (MI) indicates the high potential efficiency of the composting process due to the high temperature generation, lingering thermophilic condition, prolonged composting, and high C/N reduction.

Therefore, this test contributes to understanding stability and maturity from a microbiological basis. Its measurement is used to estimate biological activity in a sample; it refers to a specific stage of organic matter decomposition during or after composting, which is related to the type of organic compounds remaining and the resultant biological activity in the material.

Table 8. Classification of the compost samples analyzed for AT4 test [53]

Rotting class	AT4 (mg O2/g DM)	Classification of the samples tested	Product description
I	>40	0 %	Compost raw materials
II	40-28	0 %	Fresh compost
III	28-16	0 %	Fresh compost
IV	16-6	50 %	Finished compost
V	<6	50 %	Finished compost

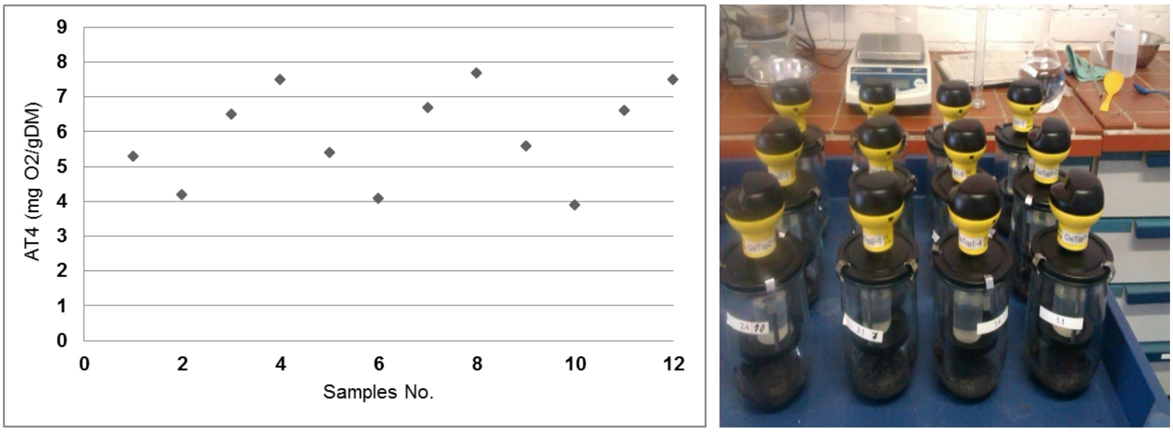

Fig. 13. Results of the AT4 test for all compost samples included in the study

The stability or maturity of the final product is of vital importance for successful agricultural application. However, an unstable compost product indicates that microbial activity is sufficiently high that it will cause adverse effects [54]. Since compost has traditionally been used agriculturally, this infers that plant growth will be negatively impacted. In other words, mature compost will exhibit characteristics that indicate completeness of the composting process. The stability of any given compost is important in determining the potential impact of the material on the nitrogen availability in the soil. Most uses of compost require a stable to very stable product that will prevent nutrient tie-up and maintain or enhance oxygen availability in the soil. As shown in Table 8, compost respiration in the samples varied from 3.9 to 7.7 mgO_2/g dm (see Figure 13). Accordingly, all of the compost samples appeared to be stable and considered as class IV and V finished products (see Figure 14).

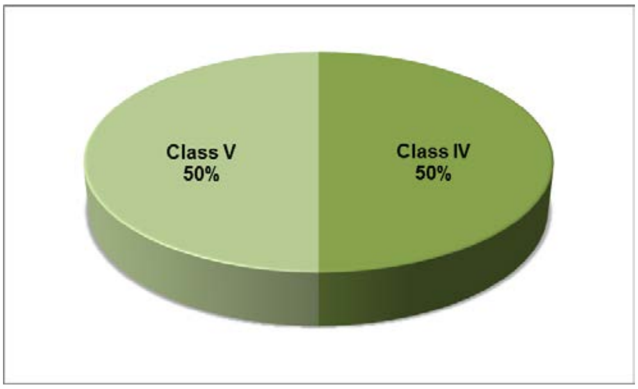

Fig. 14. Distribution of compost samples according to their rotting degree/class

The results indicated that the compost produced was quite stable and there was no more biological activity, as the organic material was destroyed to form a new stable material (soil) that can be used for agricultural purposes. This also indicates that the compost production process was performed successfully, under ideal conditions, and within a relatively short time (80 days), which, in turn, reduces the cost. Table 10 summarizes the entire results achieved at the end of all runs.

Table 9. Final physical and chemical characteristics of composting for all runs

Parameter	**P1**	**P2**	**P3**	**P4**
Ash Content (%)	40.1	43.8	39.2	39.4
Volatile Solids (%)	59.9	56.2	60.8	60.6
TOC (%)	26.9	32.6	38.8	47.9
TKN (%)	1.87	2.10	2.33	2.61
Total Organic Matter (%)	24.3	30.7	32.3	40.7
C/N Ratio (w/w)	14.4	15.5	16.7	18.4
Moisture Content MC (%)	23.0	24.0	26.0	28.0
pH	6.91	7.22	7.41	7.62
EC (dS/m)	2.76	2.80	3.54	4.09
Total P (%)	1.65	1.85	2.09	2.21
Total K (%)	1.69	1.77	1.85	1.98
Final Pile Volume m^3	25.3	28.4	27.7	31.1
Volume Reduction %	29.7	25.3	23.1	22.3
Final Bulk Density Kg/m^3	603.0	542.0	424.0	340.0
Bulk Density Increase %	15.74	14.83	14.29	15.25
Water Added m^3	21.4	22.1	21.4	24.6
m^3 water / m^3 manure	0.59	0.58	0.59	0.62
Heavy metals mg/kg				
As	< 5	< 5	< 5	< 5
Pb	2.40	1.90	2.40	< 1.0
Cd	0.39	0.28	0.32	0.19
Cr	17.0	16.0	16.0	12.0
Cu	15.0	14.0	14.0	11.0
Ni	14.0	13.0	13.0	11.0
Zn	68.0	67.0	66.0	52.0
Hg	< 0,05	< 0,05	< 0,05	< 0,05

Overall, the results of the experiment showed that compost with acceptable chemical properties (OM, TOC, TKN, total P, total K, heavy metals) and physical properties (bulk density, moisture content, etc.) was produced. These findings indicated that composting was carried out successfully under optimized conditions. It can be observed from the findings that the quality of the produced compost depends largely on the level of the C/N start-up ratio and also the quality of its constituents within the mixture.

4. Conclusions

An experimental study was carried out successively to determine some physical and chemical properties of different compost types. Four experimental windrow piles were established at different C/N ratios ranging from 24 to 29, at moisture content of 55%. The windrow piles were mechanically turned using a special compost turner. Temperatures rapidly increased from the ambient temperature up to 60-70 ºC during the first week; this range is enough for the termination of pathogens and weed seeds. Mixtures of fruits and vegetables with 10% sawdust had more thermophilic temperature development than mixtures of street plant residue and fruits and vegetables. The windrows needed 12 weeks to complete the composting phases and produce stabilised products.

The obtained results indicate that the moisture content values ranged from 23 to 28%. The pH value ranged from 6.9 and 7.6 and EC values ranged from 2.76-4.1 dS m-1 for different compost types. The total organic carbon values ranged from 26.9 to 47.9%. The total organic matter values ranged from 24.3 to 40%. The total nitrogen values ranged from 1.87 to 2.61%. The total phosphorus and total potassium values ranged from 1.65 to 2.21% and 1.69 to 1.98%, respectively, for different compost types. The C/N ratio values ranged from 14.4:1 to 18.4:1. The reduction of C/N ratio during the composting process ranged from 35-40% and the highest result was achieved in the piles with high initial nitrogen content (low initial C/N ratio). Mass losses during composting resulted in total pile volumes decreasing to a range of 22-30 %. A 15% increase in the bulk density also occurred. The bulk density value ranged from 440 to 603 kg m-3. A 1:1 ratio was assumed for the amounts of water (in volume) added in relation to the amounts of organic fertiliser (in volume) produced.

Final product quality findings showed that concentrations of all seven heavy metals (Pb, Zn, Cu, Cd, Cr, Hg and Ni) were significantly within the set limits and were much lower compared to the German standards in all piles. Compost respiration in the samples varied from 3.9 to 7.7 mgO2/g dm. All of the compost samples appeared to be stable and were considered as finished products of class IV and V.

Appropriate comparative evaluations of parametric measures in the monitored experimental windrow piles also indicated the plausibility of the following interactions in organic composting: (1) initially high C/N values were reasonably associated with lower organic matter decomposition rates and lower final humification levels; (2) higher moisture contents presumably contributed to restraining the internal temperature regime; (3) nearly horizontal or slightly increasing evolutions of extractable phosphorus and potassium contents were reasonably associated with lower slopes of increase in electrical conductivity.

Overall, the process conditions resulted in a good quality production and marketing of compost; a pathogen free product, which does not favour the growth of viable weeds and plant seeds, while it acquires sufficient organic matter content for soil fertilization.

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