Original Article

Determination of an empirical formula for organic composition of mature compost produced in Isfahan-Iran composting plant in 2013

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ABSTRACT

Aims: The aims of this study were to analyze the carbon, hydrogen, nitrogen, sulfur, and oxygen (CHNS-O) content of compost derived from Isfahan-Iran municipal solid waste using thermal elemental analyzer and to develop an approximate empirical chemical formula for the organic fraction of the mature compost as a function of its elemental composition.

Materials and Methods: The compost samples (1 kg) were collected from different parts of the windrows and thoroughly mixed in accordance with standard methods. After drying and milling, each sample was introduced to an elemental analyzer to measure their CHNS-O contents. The moisture content, temperature, and pH value were also monitored in three different windrows during the process.

Results: An approximate chemical empirical formula calculated for the organic fraction of the compost was: $C_{204}H_{325}O_{85}N_{77}S$.

Conclusion: According to this formula, it appears that the mature compost produced in the site contains higher value of nondegradable nitrogen, which leads to a lower total C/N ratio. Therefore, improving the primary separation of raw material in the composting plant particularly severance of plastic materials can result in an optimum C/N ratio.

Key words: Elemental analysis, empirical formula, municipal solid waste compost

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INTRODUCTION

Now-a-days, due to population growth, civilization and improvement of lifestyles the production of municipal solid waste (MSW) with a higher fraction of organic matter is dramatically increased. About 50% of the total MSW is comprised of organic waste that cannot be satisfactorily decomposed through natural process occurring in the environment. For this reason, organic waste has been considered as one of the greatest causes of environmental pollution.[1] Recycling of MSW contributes to the reduction of its volume, less consumption of natural resources, environmental protection, reduction of pathogens, economic development, along with other benefits to the community, and the environment.[2] Composting is a commonly used recycling method and one of the best alternatives, especially

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for biologically degradable wastes. It is the process of biological decomposition of biodegradable organic matter present in MSW under controlled conditions, so that the composted material sufficiently stabilized and sanitized for safely handling, storage and soil fertilizer.[3] The use of solid residues for the production of compost has started about a century ago and ever since, many methods have been studied.[4]

In Isfahan about 1000 tons of waste is generated daily, from which approximately 650 tons is converted to compost, 170 tons is separated and recycled from the source and 180-200 tons is segregated, compacted in the site as a dry waste and transferred to a designated place far from the city for dumping. Since 1988, when the Isfahan composting plant started to operate, its compost has been widely used for parks, recreational areas and agricultural lands. In this regard, there was always some controversy among the authorities on the public health and the sanitary aspects of the compost.[5] However, sustained process of composting eliminates most infected parasites, pathogens, and viruses. It also reduces the odors emitted by reducing hydrocarbons and drying the waste to be composted; this phenomenon makes it unattractive to insects.[6] Composts produced from MSW contain a substantial organic fraction and are rich in nutrients that improve the properties of soil.[7-9] It was shown that applications of MSW compost increase the total porosity of soil, water retention in soil, and improve water penetration, air circulation, and the stability of soil aggregates.[3,8,10,11]

The organic matter of soil in Isfahan is very low due to limited precipitation, so that, every effort that could lead to increase the soil organic matter such as an addition of high quality compost is valuable.[12] Provided that, in the compost production process and its distribution, the health and environmental aspect and plant health should be considered. Thus, monitoring the quality of the final compost is very important to ensure its maturity that is a suitable alternative for chemical fertilizer and does not contaminate the environment.[10] The main objective of this study was to analyze the carbon, hydrogen, nitrogen, sulfur, and oxygen (CHNS-O) content of MSW compost produced in Isfahan composting plant through windrow method and thereby to develop an approximate empirical chemical formula for the compost. This can be a simple qualitative indicator of the compost, which is useful for its proper application.[13] Physical parameters such as temperature, moisture content, and pH were also measured throughout the composting process.

MATERIALS AND METHODS

Sample collection and preparation

At the final day of the composting process in the Isfahan composting plant, 15 samples with the amount of 1 kg each were randomly collected from three windrow using standard methods (3 samples, one from one-third of the top, other from the center and the third from one-third of the bottom of the windrow were collected and mixed thoroughly). According to the dimension of the windrow piles (30 m in length, 2.5 m width and 1.5 m height) 5 samples each with a 5 m interval were taken throughout each windrow. The samples were transferred to the reference laboratories of the department of environmental health engineering in the Isfahan University of Medical Sciences for analysis. The samples were dried in the room temperature for 2 days, then the dried materials were ground using a crushing machine (model Bench Grinding 300P) and mixed to obtain a homogeneous mixture ready for analysis.

Analysis of the carbon, hydrogen, nitrogen, sulfur and oxygen and C/N ratio of the mature compost

An automated thermal elemental analyzer (ECS 4010 CHNS-O elemental Analyzer, Costech Analytical Technologies, Inc., Italy) was employed to determine the amount of elemental CHNS-O in the compost samples. This high-temperature combustion system provides immediate results in the conversion of substances into gases. A small amount of sample in a capsule drops inside an oxidation/reduction reactor kept at a temperature of 1000°C. A certain amount of oxygen enters into the combustion reactor at a precise time. Exothermic reaction between oxygen and encapsulated sample increases the temperature to 1800°C for a few seconds. At this temperature, both organic and inorganic compounds are converted into elemental gases, which are separated by chromatography and detected by a thermal conductivity detector. To prepare the samples, 2-10 mg of dried and milled samples was encapsulated by aluminum foil and placed into the auto-sampler stages of the elemental analyzer. The instrument was calibrated by different standards before introducing the samples. For oxygen analysis, the system needs a nickel coated carbon as a reaction media, which was not available in the laboratory. Hence that, the oxygen content of the samples was determined just by calculation using the following formula:

$$\text{Oxygen }\% = 100 - (C\% + H\% + N\% + S\% + Ash\%)$$

This is an approximate prediction of oxygen content of the compost that contains.[14] The fixed ash fraction of the samples was determined by weighing out a predried sample at 105°C, combustion in a muffle furnace (Isuzu, Sehisakusho, Japan) at 550°C for 2 h, weighing out the residue after cooling in dedicator and then calculating the remaining mass.

Furthermore, the amount of available carbon in the compost was measured by determining the ash content of the samples using a muffle furnace (Isuzu, Sehisakusho, Japan) at 750°C for 2 h, and then applying the following formula:[15]

$$C = \frac{100 - Ash}{1.8}$$

Available nitrogen of the compost samples was measured using an automated distillation system according to the following procedure: a Kejeldahl tablet as a catalyst and 7cc of concentrated sulfuric acid were added to 0.5 g of the prepared samples (dried and milled) inside a 10 ml vial and left at room temperature for 24 h for stabilization. Later, the vial was placed into the distillation system, and the temperature was increased from 120°C to 390°C gradually. After that, the samples were titrated with hydrochloric acid 0.25% until converting their color from light green to dark, and the volume of acid was recorded. Finally, the amount of nitrogen was calculated according to the following equation:[16]

$$N = \frac{(a-b) \times n}{m} \times 1.4$$

Where: '*a*' and '*b*' stands for the volume of acid used for the sample and blank titration, respectively, '*n*' is normality of the acid and 'm' is the sample dry weight. Using these data, the C/N ratio of the compost samples was calculated among the composting process.

Temperature, pH, and moisture measurement of the raw compost

During the composting process before achieving the full maturity of the compost, its physical parameters such as temperature, humidity and pH were monitored. To do this, the samples of 1 kg were simultaneously taken from three different compost piles among a composting cycle with 2 weeks interval for 3 months (July, August, and September 2013). The piles temperature was measured spontaneously at the site, but the samples were transferred to the reference laboratories in the Department of Environmental Health Engineering, Isfahan University of Medical Sciences for analysis of the pH and moisture content. The temperature was measured by a Saey rod thermometer (Germany) with a rod length of 90 cm suitable for windrow piles. In the laboratory to measure the pH, about 50 ml distilled water was added to the 10 g previously dried compost (in a 105°C oven for 24 h), mixed thoroughly for 1 min and let to stand for 10 min to make a slurry with a ratio of 1:5.[17] Then, the pH was read with a calibrated pH meter (CG, Model 824, Schott, UK Ltd, UK) and the results were recorded. Gravity method was applied to measure moisture in the compost samples by calculation of the mass loss of the samples when kept at 105°C in an oven (Memmert, GmbH, Germany, Model D-91126, Schwabach) for 24 h.

RESULTS

Table 1 shows the percentage of total CHNS-O in 15 samples taken from the mature compost as well as the C/N ratio of the samples. The CHNS-O variations throughout different parts of a composting windrow pile in the final processing day are shown in Figure 1.

Table 2 outlines the amounts of pH, temperature and humidity throughout the composting process and their averages in different windrows, which were sampled and analyzed with 2 weeks interval within 85 days. The amounts of available C/N ratio of the samples are also presented in Table 2. Variations of the temperature, pH value and moisture content in different windrows throughout the composting process are illustrated in Figure 2.

Using the obtained analytical data the approximate chemical empirical formula calculated for the organic fraction of the mature compost was: $C_{204}H_{325}O_{85}N_{77}S$.

DISCUSSION

Carbon, hydrogen, nitrogen, sulfur and oxygen content and C/N ratios

According to Table 1, the results obtained through thermal elemental analysis of all the collected samples indicated

Table 1: Total carbon, hydrogen, nitrogen, sulfur, and oxygen content of the compost samples

Sample number	Carbon %	Hydrogen %	Nitrogen %	Sulfur %	Ash %	Oxygen %	C/N ratio
1	30.26	4.77	12.55	0.19	35.68	16.55	2.41
2	36.64	4.96	16.28	0.55	21.29	20.28	2.25
3	21.35	3.33	16.30	0.16	44.81	14.05	1.31
4	28.76	3.74	17.12	0.24	32.23	17.91	1.68
5	28.87	3.85	9.82	ND	42.07	15.39	3.00
6	26.35	3.45	10.93	0.17	45.52	13.58	2.41
7	26.11	3.21	10.83	ND	45.78	14.07	2.43
8	33.18	4.30	13.76	0.13	30.75	17.88	2.41
9	29.14	3.86	12.09	0.16	38.18	16.57	2.41
10	32.29	4.12	13.39	0.73	31.64	17.83	2.41
11	30.47	4.00	12.64	0.31	35.86	16.72	2.41
12	32.49	4.43	13.48	0.88	30.99	17.73	2.41
13	30.71	3.95	12.74	ND	35.73	16.87	2.41
14	28.97	3.76	12.02	0.94	36.94	17.37	2.41
15	29.14	3.86	12.09	ND	39.16	15.75	2.41
Average	29.65	3.97	13.07	0.39	36.44	16.57	2.32
SD	3.52	0.49	2.10	0.28	6.63	1.78	0.38

ND: Not detected

that the average elemental carbon content of the mature compost was 29.65%. The minimum amount of carbon was detected in the sample 3 namely 21.35% and the maximum in the sample 2 amounting 36.64%. The hydrogen content of the samples was in the ranges of 3.21-4.96% with an average of 3.97%. The nitrogen content of the samples ranged from 10% to 17% with the average amount of 13.07%. Variation in the amounts of the analyzed elements indicated that the compost throughout the windrow is not properly commingled. The higher value of nitrogen in some samples shows that the compost of belonging site is immature and not well-stabilized. The sulfur content of all samples was <1%

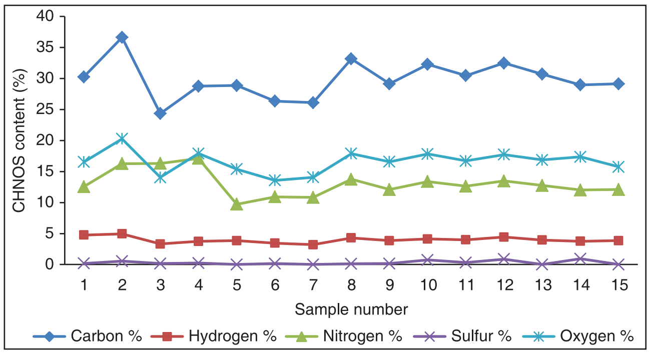

Figure 1: Carbon, hydrogen, nitrogen, sulfur, and oxygen variation in the compost samples collected from different parts of the windrows in final processing day

Table 2: Amounts of temperature, pH, moisture and available C/N ratio during the composting process and their averages in different windrows

Windrow number	Week	Temperature (°C)	pH	Moisture (%)	C/N ratio
1	2	54	5.5	48	21.2
	4	55	6	46	20.5
	6	62	6.8	42	19.4
	8	65	7.2	37	18.1
	10	64	7.5	38	17.2
	12	56	7.8	47	17.0
Average		59.3	6.8	43.0	18.9
2	2	48	5.3	51	20.1
	4	49	5.8	50	19.6
	6	55	6.5	46	18.3
	8	57	7.5	45	17.4
	10	59	7.7	45	16.2
	12	60	7.5	43	15.1
Average		54.7	6.7	46.7	17.8
3	2	51	5.8	49	19.4
	4	55	6.2	46	18.9
	6	60	7.3	43	18.5
	8	62	7.7	42	18.1
	10	58	7.4	45	17.3
	12	61	7	42	16.2
Average		57.8	6.9	44.5	18.1

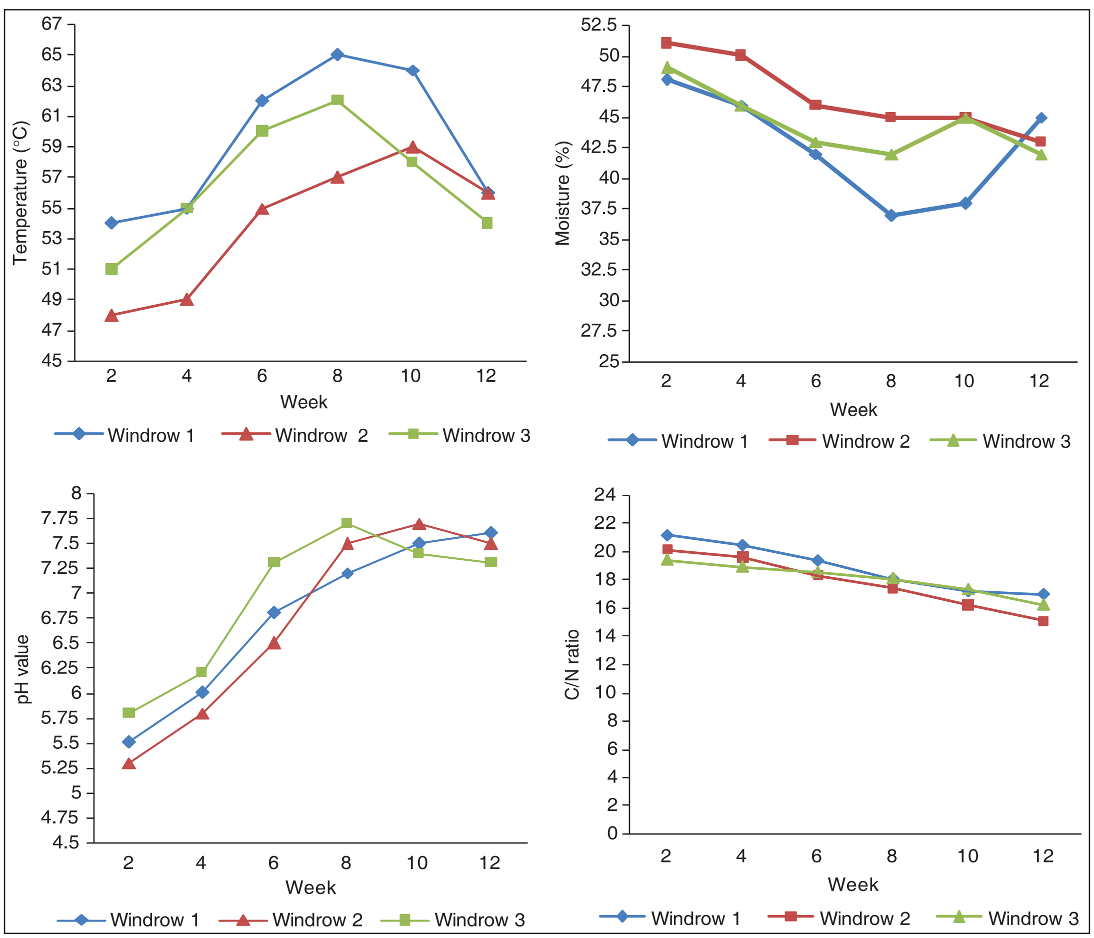

Figure 2: Variation of temperature, pH, moisture, and available C/N ratio in different windrows among the composting process

with an average of 0.39%; however, in some samples, it could not be detected correctly. These results are in agreement with the results of a similar research conducted by Komilis,[13] who could not particularly detect sulfur in most of the samples taken from various types of compost. The oxygen content of all samples varied from 41% to 59% and generally was higher than other elements in this study.

The C/N ratio presented in Table 1 was calculated using the total carbon and total nitrogen analyzed by elemental analyzer. As it includes all the organic and fixed carbon and nitrogen, the average of C/N ratio obtained here was very low namely 2.32% ± 0.38%. Thus, it cannot be considered as a proper indicator of mature and stable compost. However, the amount of total C/N ratio for the mature compost, which probably will be added to the soil as a supplement is very small. Therefore, it cannot account for as high quality compost.

The average available C/N ratios of the compost in different windrows were within the optimum range namely between 17.8 and 18.9 [Table 2]. As shown in Figure 2, their variation trends among the process were not significant. However, there were slight reductions in the C/N ratios, which indicate the higher rate of carbon loss compared with nitrogen loss. Ammonia volatilization and bio-oxidation is the main reason for these losses.[18] Operating with a reduced turning frequency and C/N ratio of 25/1 gives a minimum nitrogen loss[19] Initial available C/N ratios between 25 and 50 are optimum for aerobic composting of MSW, and that of in the stabilized compost should be somehow between 10 and 20.[2] At lower C/N ratios ammonia is given off, and the biological activity is also impeded. At higher ratios of C/N, nitrogen may be a limiting nutrient.[2] In a similar study, the C/N ratio of the stack piles has been decreased from 35/1 to 12.5/1 during the composting of MSW.[20] According to the results of analytical and comparative analysis, the following empirical chemical formula for CHNOS was obtained: $C_{204}H_{325}O_{85}N_{77}S$. According to this formula it appears that the mature compost produced in the site contains higher value of nitrogen, which leads to lower C/N ratio [Table 1]. Therefore, improving the primary separation of raw material in the composting plant can result in an optimum C/N ratio.

Temperature, pH and moisture variations

Temperature

The microorganism activities are strongly temperature dependence. During the composting process temperature increases due to aerobic biological activities, in which three thermal phases including premesophilic, thermophilic and postmesophilic are distinguished.[2] In real operational conditions, optimum temperature for windrows is thermophilic because most pathogens, parasites and weeds are destroyed at this temperature. According to Table 2, in the 1st month of operation the temperature range of the windrows was 48-55°C, which is favorable for composting. It continues rising among the 2nd month and reaches to its maximum at the end of the month ranging from 57°C to 65°C. This indicates that the compost has entered to the active phase and as long as the biodegradable substances are available the temperature remains at its highest level.[2] In a previous study, at this composting site a maximum temperature of 61°C has been recorded in the thermophilic phase.[21] In another study, producing compost by stack methods a maximum temperature of 65°C has been achieved in the compost pile at the 9th day of operation.[20] It should be noted that the effect of environmental temperature at any ranges on the windrow temperature cannot be ignored. In the 3rd month of operation, the temperature started to decline, whereas it reduced to 56-61°C within the windrows at the end of the month, which is attributed to the reduction of bacterial activity due to the decomposition of biologically available components. In general, a temperature window of 40-65°C is more favorable for the composting process. Temperatures higher than 65°C destroy the useful microorganisms and lower than 40°C inhibit the microbial activities.[22]

Monitoring the pH

Microorganisms can be active in different pH levels preferably from 5.5 to 8.[2] In the composting process controlling the pH can provide growth and action of bacteria. In this study, the pH of the windrows was monitored within 3 months of composting with 2 weeks interval. Figure 2 shows during the 1st month the pH levels of the windrows was between 5.5 and 6.2, which indicates the acidic phase due to the predominance of fungi and acid producing bacteria at this stage.[2] Among the 2nd month due to the use of organic acids by microorganisms the pH levels has the desire to increase up neutral range as well as slightly alkaline. However, from month 3 it started to slightly reduce and then stabilized at the end of the month.

Moisture contents

The humidity between 45% and 50% is an optimum range for the composting process.[2] In humidity <30%, the bacterial activities will be limited and that above 65% will decrease the porosity of the compost resulting anaerobic growth and unpleasant odor emissions.[23] As shown in Figure 2, variation of the moisture content of the monitored windrows had normal trends starting from 46% to 51% in the 1st month and lowering to 42-47% at the end of 3rd month operation. However, the moisture content of the first windrow was lower than others, which may be attributed to the higher paper content of its raw materials. Manually spraying the water on the first windrow within the 3rd month caused its humidity to be increased. Nevertheless, humidity ranges appeared to be ideal for the composting process in this study.

CONCLUSIONS

Using the results obtained by thermal elemental analysis of the waste derived compost an empirical formula of

"$C_{204}H_{325}O_{85}N_{77}S$" was calculated. The amount of total nitrogen measured in the mature compost at the time of this study is very high, which results in a low amount of C/N ratio in the mature compost. This is probably attributed to the presence of nondegradable components such as lignin and cellulose. However, during the process the amount of available nitrogen for the microorganism in the windrows was much higher than the total nitrogen. Thus, the available C/N ratios of the compost in different windrows throughout the process are at logical range namely between 17.8 and 18.9. Therefore, to solve this problem in the Isfahan composting plant one suggestion is improving the separation system of raw MSW. Monitoring the physical properties of the compost throughout the process showed that they are nearly in an acceptable level.

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