Review Article

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Quality assessment of compost prepared with municipal solid waste

https://doi.org/10.1515/eng-2017-0028
Received Mar 29, 2017; accepted Aug 04, 2017

Abstract: One way that helps maintain the sustainability of agro-ecosystems land is the application of compost from municipal solid waste as fertilizer, because it can recover the nutrients contained in them, minimizing the negative impact on the environment. Composting as a method for preparing organic fertilizers and amendments is economically and ecologically sound and may well represent an acceptable solution for disposing of municipal solid waste. In the present work, the quality of compost is studied made from municipal solid waste; the content of mineral nutrients: potassium, calcium, magnesium, sodium, zinc, manganese, cupper, iron, nickel, chromium and lead has been investigated. The objective was to evaluate the changes in mineral nutrient concentration during the composting process. The compost was prepared in a pilot-plant using the turning-pile system. Temperature was used as a monitoring parameter to follow the composting progress, which underwent the typical trend of municipal solid waste composting mixtures. The results showed a similar evolution on the content of mineral nutrients of the mixture of municipal solid waste. This evolution originated in a mature compost (end sample) with an adequate content of mineral elements and physical-chemical characteristics for its use in agriculture. So, the use of compost of municipal solid waste represents an important tool for fertilization requirements for its use in agriculture.

Keywords: composting, mineral element, waste management

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1 Introduction

Formerly, the disposal of waste resulting from human activities did not pose a serious environmental problem because the population was small and the amount of land available for assimilation was great. However, with the development of modern societies in which raw consumerism and the culture of "throwaway" is on the agenda, the problem of urban solid waste is becoming ever greater.

One of the main characteristics of bio-waste is the heterogeneity of its composition. That is, the composition of this fraction of municipal waste depends on factors such as the nature of its composition and origin, the season of the year in which we find ourselves and the type of eating habits that the population has. Despite the variability of composition, there are some elements that will always be present in the mixture of bio-waste: water (in a variable proportion, but generally estimated around 80%) and elements derived from its composition in organic matter, such as carbohydrates, proteins and fats. However, it is not possible to speak of a single proportion of such elements by the variability or heterogeneity mentioned above. As a consequence of these characteristics, the treatment of these residues is that of composting instead of incineration.

The production of compost has long been the object of great interest to researchers, since compost may be used as a fertilizer or as a material for producing plant nursery substrates. From an economic point of view, composting can therefore bring reductions in the cost of disposing of organic residues, as well as providing an income, by virtue of compost being used as a substitute for other materials (chemical fertilizers and peat) that may be quite expensive. In addition, composting can have a strong ecological environmental value, allowing organic by-products to be subtracted from the disposal cycle and put back into the production cycle, enhancing it and closing the organic carbon cycle, while also being a tool for the economic and social sustainability of production activities in rural areas [28, 30], also in accordance with the European strategy "Horizon 2020 for rural sustainable development.

The last report of The World Bank estimates that the current worldwide average generation rate of Municipal Solid Waste (MSW) per capita in urban areas corresponds to approximately 1.2 kg per person per day and that by 2025 this will likely increase to 1.42 kg/person/day, reaching 2.2 billion tonne of waste per year on a global scale [14, 19]. In general, it is established that in Europe the most predominant form of waste treatment consists of landfilling or filling operations, followed by recycling, incineration and finally composting. So, the concrete data for 2012 and 2014 in Spain from the Eurostat database (http://ec.europa.eu/eurostat), the waste management is mostly landfilling (60.57% in 2012 and 57.70% in 2014). However, it can be seen that in the last two years there has been a reduction of this treatment method (−10.31%), increasing the popularity of other methods such as incineration (11.78%) and composting (22.43%). Recycling experienced a substantial percentage reduction during this period (−21.30%).

In accordance with the last trend of environmental policies, composting is a valuable way of waste treatment that contributes to reduce organic waste destined to landfill disposal or incineration. Home and community composting have proven to be a sustainable strategy for food waste management that can reduce costs and environmental impact due to collecting, transport and treatment of MSW [5, 26]. Composting is a low temperature bio-oxidative process with a stage of the organic matter degradation and the mineralisation of labile organic compounds (readily available for the microorganisms) and belongs to important trends in recycling organic and mineral components of wastes [3]. So, composting is a method for preparing organic fertilizers and amendments economically and ecologically sound and may well represent an acceptable solution for disposing of municipal solid waste, at the same time increasing its value [1, 9, 21, 24]. The application of compost from municipal solid waste as fertilizer maintains the sustainability of agro-ecosystems land because it can recover the nutrients contained in them, minimizing the negative impact on the environment [15].

Composting provides a valuable material improving physical and chemical properties of soil. For example, the agroindustry waste compost application in soil showed a significant increase in the nitrogen, phosphorus, potassium and organic matter content in amended plots [11].

The quality of the obtained compost depends to a great extent on the kind of material subjected to stabilisation. In the case of municipal wastes this method is extremely advantageous since it eliminates their sanitary-epidemiological hazard, bacteria and fungi with high temperature; and reduces the organic content of landfills, source of the development of undesirable microorganisms and the high risk to the proliferation of infections. Among other advantages of the method, there are its availability, easy exploitation, when there is a separation of inert materials in the waste management, and the possibility of obtaining soil amendment improving its fertility [20, 25, 32].

However, a decisive criterion for the usefulness of the product is its quality [17]. The product obtained as a result of composting municipal waste and sewage sludge is rich in humus and macro and microelements [16]. The only problem is the increase in heavy metal content [12, 22]. High concentration of heavy metals in obtained product may exclude the possibility of their use in agriculture [16], especially those produced from municipal waste [7, 27].

In the present work, we studied the quality of compost made from municipal solid waste and the content of mineral nutrients (K, Ca, Mg, Na, Zn, Mn, Cu, Fe, Ni, Cr and Pb). The objective was to evaluate the changes in mineral nutrient concentrations during the composting process.

2 Material and methods

2.1 Compost production

Three different composting piles were prepared by municipal solid wastes (MSW) with selective separation of metals. All these wastes are produced locally in the population in the surrounding area. The efficient recycling of these wastes contributes to a sustainable agricultural production system in the society. These composts were prepared on two consecutive years using the same dry weight proportions of the received municipal solid wastes after of the selective separation and homogenized to achieve an initial C/N of 30.

Composts were prepared in a pilot-plant using the turning-pile system in trapezoidal piles (10 m length, 2 m width on the base and 3 m height) containing approximately 450 tons each pile. The piles were turned every ten days during the bio-oxidative phase (approximately 12 weeks, from July to September) and the mixtures were then allowed to mature over a period of one month. Temperature and moisture were used as monitoring parameters to follow the composting progress. Urban waste water and water from sewage treatment plants were added during turning to keep the moisture levels in the range between 40 and 60%.

2.2 Analytical methods for samples

The moisture of the composting samples was determined after drying at 105°C for 12 h.

The following elements were analyzed: K, Ca, Mg, Na, Zn, Mn, Cu, Fe, Ni, Cr and Pb. The analysis of the mineral elements was carried out according to the procedure described by Fernández-Hernández et al. (2010) with some modifications. The samples were burned in a muffle furnace at 450°C for 12 h and the ashes were dissolved in concentrate HNO_3, taking it to a final volume of 50 mL with 2% HNO_3 (v/v). The concentrations of the eleven elements studied (K, Ca, Mg, Na, Zn, Mn, Cu, Fe, Ni, Cr and Pb) were measured by using an Agilent model 7500A ICP-MS instrument equipped with an octapole collision cell and autosampler.

2.3 Statistical analyses

The experimental data were subjected to a one-way analysis of variance (ANOVA) and mean separations were performed by the least significant difference (LSD) at the level of significance of $P < 0.05$, by using the Statistix 8 program for Windows.

3 Results

3.1 Compost characterization

As shown in Figure 1 the composting piles temperature went through three typical phases (heating, thermophilic and cooling phase) and ranged from 22°C to 72°C during the entire period of composting. These results indicate quick establishment of microbial activity in the composting piles. These results indicate that the municipal solid waste might have enhanced the composting process by providing easily available carbon for microorganism which is required for their growth.

The thermophilic phase showed the higher temperature (60-72°C) (Figure 1). This temperature has been kept from the second week to seventy days, fifty two days approximately, during the composting process. This trend has been observed for all the urban solid wastes piles. The differences between the pile temperature can be explained by the unsuitable materials exercising some structuring effect. As it has been reported in other studies lignocellulosic wastes in composting mixtures (Serramiá et al., 2010), characteristics of these unsuitable materials could

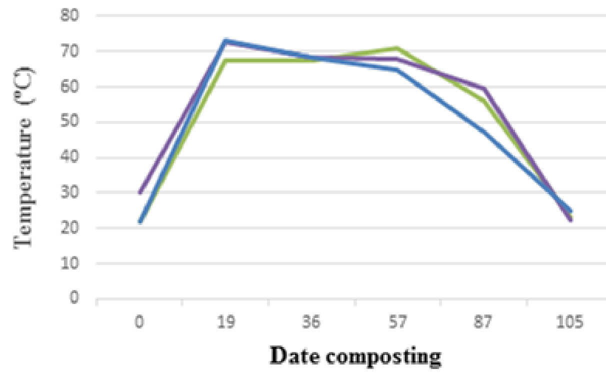

Figure 1: Evolution of temperature during composting process in municipal solid waste (MSW) in three different piles.

inhibit the microbial attack, slowing down the degradation of the mixture during composting.

3.2 Mineral composition of the municipal solid waste compost samples

Composts prepared for the present study showed a relatively high content in mineral elements (Table 1) making them suitable for their use as organic fertilizer on agricultural land. The mineral composition of composts is highly dependent not only on the composition of the raw materials itself but also on other external factors such as the rate and composition of the municipal solid waste used in the starting mixtures.

Table 1: Mineral elements content on dry matter in municipal solid wastes mixtures prepared during the composting. Results expressed as mean values ± standard deviation (n=9).

Mineral Element	Minimum content (µg/Kg)	Maximum content (µg/Kg)
K	65676±925	157221±872
Ca	230410±425	748154±737
Mg	23953±459	76208±796
Na	47829±431	85689±406
Zn	364±10.3	3148±97.3
Mn	208±46.0	994±64.2
Cu	136±35.8	1144±58.5
Fe	3149±152	40498±264
Ni	25.8±1.12	130±10.6
Cr	90.6±17.4	648±77.5
Pb	27.8±7.31	262±12.7

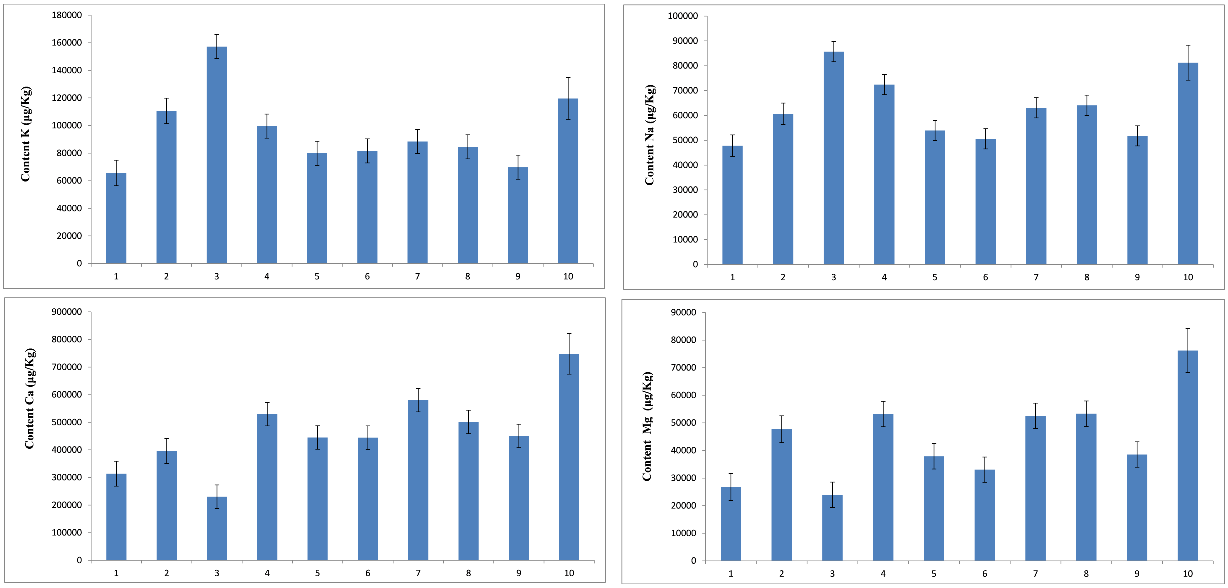

Figure 2: Mineral content evolution during composting process for K, Ca, Mg and Na. Results expressed on dry matter and error bars are standard deviation of the means (n=9). Date of sample: 1 (14.07.2014), 2 (28.07.2014), 3 (11.08.2014), 4 (18.08.2014), 5 (25.08.2014), 6 (08.09.2014), 7 (15.09.2014), 8 (22.09.2014), 9 (06.10.2014) and 10 (20.10.2014).

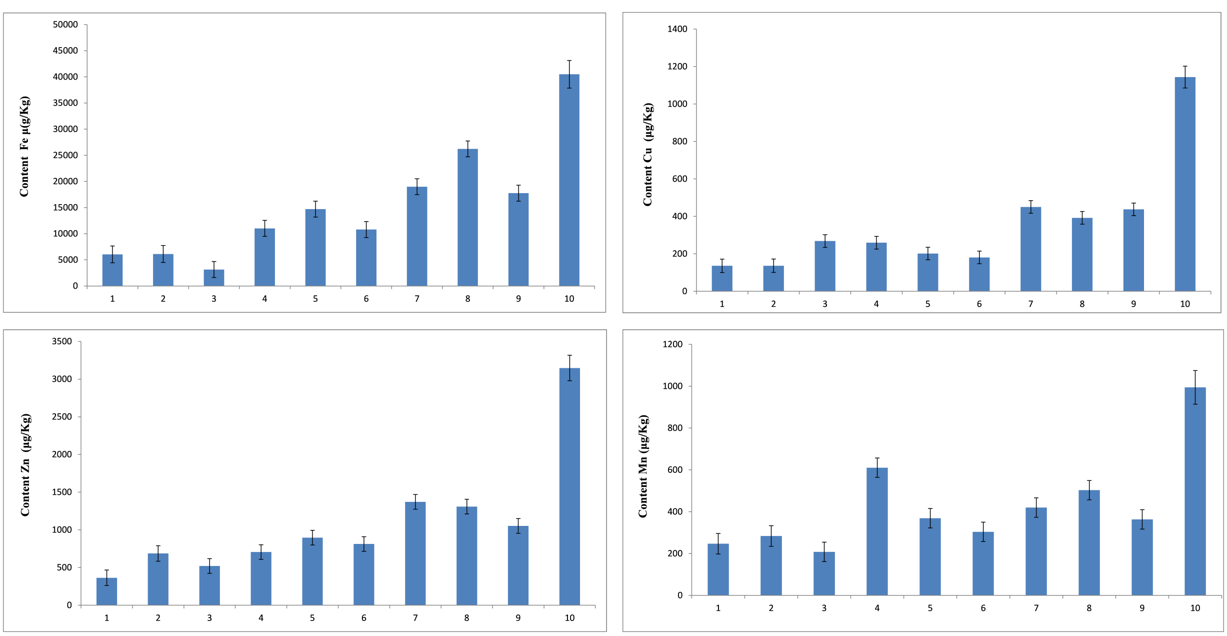

Figure 3: Mineral content evolution during composting process for Fe, Cu, Zn and Mn. Results expressed on dry matter and error bars are standard deviation of the means (n=9). Date of sample: 1 (14.07.2014), 2 (28.07.2014), 3 (11.08.2014), 4 (18.08.2014), 5 (25.08.2014), 6 (08.09.2014), 7 (15.09.2014), 8 (22.09.2014), 9 (06.10.2014) and 10 (20.10.2014).

According to the results in Figure 2, potassium and sodium were available in the samples of municipal solid waste compost in large quantities, with an average value of 95.70 ± 9.47 and 63.12 ± 4.41 mg/kg on a dry matter basis, respectively. The data show the same trend during the composting process with a significant increase in potassium and sodium from the compost during the initial stage of it. But it declines sharply at the end of the composting for both mineral elements.

Calcium is generally one of the major elements in municipal solid waste compost. The average value obtained in the samples studied was 46.40 ± 4.62 mg/kg on a dry matter basis (Figure 2). The lowest value of calcium was found in compost samples from initial stages, while the highest

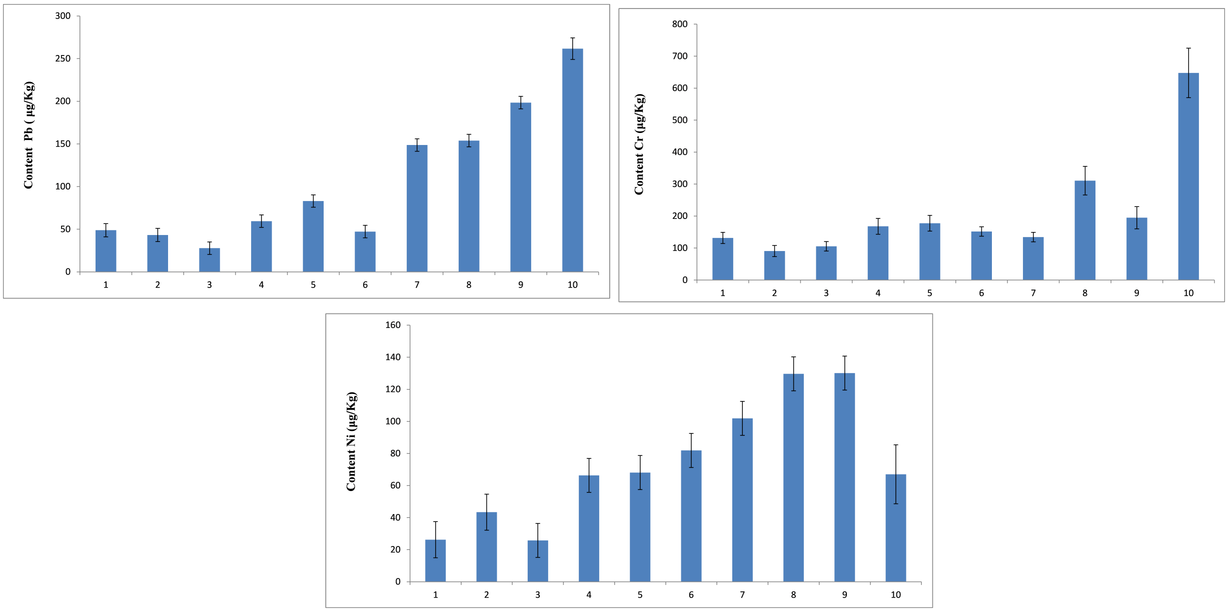

Figure 4: Mineral content evolution during composting process for Pb, Cr and Ni. Results expressed on dry matter and error bars are standard deviation of the means (n=9). Date of sample: 1 (14.07.2014), 2 (28.07.2014), 3 (11.08.2014), 4 (18.08.2014), 5 (25.08.2014), 6 (08.09.2014), 7 (15.09.2014), 8 (22.09.2014), 9 (06.10.2014) and 10 (20.10.2014).

were detected in mature compost samples. According to the results shown in Figure 2 the concentrations of magnesium in the samples of municipal solid waste compost ranged from 26.79 ± 4.87 mg/kg to 76.20 ± 7.96 mg/kg on a dry matter basis in mature sample. Calcium and magnesium content in compost samples during the composting process showed the same trend (Figure 2).

The changes in water-soluble metals (Fe, Cu, Zn and Mn) during the municipal solid waste composting process, expressed in μg/kg, are presented in Figure 3. The amount of these metals in the compost shows a significant difference in their results at the end of the composting. The concentration of Fe, Cu, Zn and Mn were increased in the compost at the maximum values of 40000, 1100, 3300 and 1000 μg/kg, respectively.

Figure 4 shows the average concentration for Pb, Cr and Ni obtained for the mature compost samples collected. Lead is one of the heavy metals found in the highest proportions in the samples of municipal solid waste compost. As shown in Figure 4 the average value for lead concentration was of 107.22 ± 7.93 μg/kg. According to the results in Figure 4, the chromium content in the municipal solid waste compost samples had a mean value for the samples studied of 211.25 ± 28.53 μg/kg on a dry matter basis, lower than that reported by Hernandez et al. (2015). From the results shown in Figure 4, it may be seen that Ni concentrations were generally low in all the samples, all the values meeting the requirement of quality B: 90 mg/kg [6]. The mean value for all the samples of municipal solid waste compost was 74.04 ± 11.51 μg/kg on a dry matter basis. This value was lower than between those found by other authors like Hernandez et al. (2015).

4 Discussion

The temperature curve described during the composting has followed the normal guidelines to obtain a correct process and establish that it is possible to obtain a compost of municipal solid waste. The process reaches temperature higher than 68°C-70°C for more than 48h which allows the sanitation of the starting materials to avoid the proliferation of fungi and/or bacteria in the crops where the compost will be applied. In addition, the temperature curve described during the process confirms that the municipal waste presents a lignocellulosic fraction that allows the microbial activity for the degradation of the same. So that, the nutrients present in municipal waste will be available to the crops.

The composts prepared in this experiment showed similar mineral composition and physio-chemical characteristics (Table 1) to other composts prepared from different agro-industrial by-products which are commonly used as organic fertilizers [11] with an important quantity of other plant nutrients such as K, P, Ca, Mg and Fe [2, 8, 13]. Mineral composition of the municipal solid waste compost samples has a high capacity to supply these mineral elements to plants. The mineral element content in the compost elaborated is lower than those reported recently by other authors such as Castaldi et al. (2017), Montejo et al. (2015) or Barral et al. (2009) in municipal solid waste compost but these differences may be responsible for the high percentage of impurities in the analyzed samples and to the influence of external parameters as the climatology (temperature and rain), raw materials composition and year season.

The potassium, sodium, calcium and magnesium concentration (Figure 2) trends to increase with the degree of maturation during the first stages of the composting. The mineralization of the organic fraction during the composting originates the loss of weight that would explain the increasing of their content in the final compost as it was observed by other authors [18]. In the case of potassium and sodium (Figure 2), the evolution can be due to the addiction of urban waste water and sewage during the turning of the piles for maintaining the moisture in the composting process.

The mean value of pH during the composting was alkaline (pH = 8.5) and it produced a mineralization of mineral elements. For example, the iron content (Figure 3) was being accumulated during the process due to the lower solubility in these conditions of pH. This is very important for the availability of them, when they are used in agriculture. The higher content in organic matter enables the accumulation of mineral elements as iron, copper, zinc and manganese in the compost. The organic amendments, with lower maturity and stability, is due to the initial incomplete separation of impurities in the raw materials.

The heavy metal content, nickel, lead and chrome (Figure 4), showed lower variability during the process of composting but, in the final stage (mature compost) the content increased considerably due to the elimination of impurities during the maturation stage. The results were compared to the Spanish standard requirements related to fertilizer products [6], in which heavy metal concentrations in municipal solid waste compost are restricted. In accordance with this regulation, three categories of compost (quality A, B and C) (Table 2) can be established as a function of threshold concentration of heavy metals: the lowest level (most restrictive) corresponds to compost of quality A while the most permissive level, which must not be exceeded, is called quality C. So that, the compost elaborated belongs to the category B (Table 2).

In summary, mature municipal solid waste compost showed quality enough to be used as fertilizer or agricultural substrate by their content in micro and macronutrients. The municipal solid waste composting has been considered as a method for the environmental management of these wastes, being economically and ecologically viable.

Table 2: Content heavy metals in municipal solid waste compost according to the Normative (Real Decreto 506/2013).

Element	Content (mg/kg)		
	Quality A	Quality B	Quality C
Cd	0.7	2	3
Cu	70	300	400
Ni	25	90	100
Pb	45	150	200
Zn	200	500	1.000
Hg	0.4	1.5	2.5
Cr	70	250	300

Acknowledgement: We acknowledge support provided by research group PAIDI RNM-296 and project MINECO CGL2013-48843-C2-1-R. The authors are grateful to Centro de Instrumentacion Científico-Técnica (CICT) from the University of Jaén for the availability of the ICP-MS instrument.

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