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Stability and maturity of biowaste composts derived by small municipalities: Correlation among physical, chemical and biological indices

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Stability and maturity are important criteria to guarantee the quality of a compost that is applied to agriculture or used as amendment in degraded soils. Although different techniques exist to evaluate stability and maturity, the application of laboratory tests in municipalities in developing countries can be limited due to cost and application complexities. In the composting facilities of such places, some classical low cost on-site tests to monitor the composting process are usually implemented; however, such tests do not necessarily clearly identify conditions of stability and maturity. In this article, we have applied and compared results of stability and maturity tests that can be easily employed on site (i.e. temperature, pH, moisture, electrical conductivity [EC], odor and color), and of tests that require more complex laboratory techniques (volatile solids, C/N ratio, self-heating, respirometric index, germination index [GI]). The evaluation of the above was performed in the field scale using 2 piles of biowaste applied compost. The monitoring period was from day 70 to day 190 of the process. Results showed that the low-cost tests traditionally employed to monitor the composting process on-site, such as temperature, color and moisture, do not provide consistent determinations with the more complex laboratory tests used to assess stability (e.g. respiration index, self-heating, volatile solids). In the case of maturity tests (GI, pH, EC), both the on-site tests (pH, EC) and the laboratory test (GI) provided consistent results. Although, stability was indicated for most of the samples, the maturity tests indicated that products were consistently immature. Thus, a stable product is not necessarily mature. Conclusively, the decision on the quality of the compost in the installations located in developing countries requires the simultaneous use of a combination of tests that are performed both in the laboratory and on-site.

1. Introduction

Composting is one of the most applied and effective technique for the treatment of the organic fraction of municipal solid wastes (biowastes) (Levis et al., 2010). In order to guarantee the safety of compost during its use in the agriculture, or as an amendment in degraded soils, certain quality criteria should be fulfilled. These are related to the content of pathogens, heavy metals, organic matter, nutrient content, stability and maturity (Soumaré et al., 2003; Tognetti et al., 2007; Barral et al., 2007).

Stability is a term related to the resistance of the organic matter of a product against extensive degradation or toward major microbiological activity. Maturity describes the ability of a product to be used effectively in agriculture and is related to the growth of plants and to phytotoxicity aspects. In general, both criteria should be somehow correlated, since phytotoxic compounds are products of the microbial activity of unstable organic matter (Sullivan and Miller, 2001; Bernal et al., 2009; Komilis and Tziouvaras, 2009; Raj and Antil, 2011; Astrup et al., 2015). That is, an unstable or immature organic product hinders the growth of plants and negatively affects the quality of soil (Riffaldi et al., 1986; Wu et al., 2000; Tang et al., 2003).

A large number of physical, chemical and biological tests has been proposed to assess the stability and maturity of compost

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(Bernal et al., 1998, 2009; Barrena et al., 2006); however, there is still no unique universally accepted test to assess both parameters (Komilis et al., 2011). Among the tests used, we can find some commonly used on-site and others that need a laboratory to be performed. The latter are usually characterized by complexity or demand higher costs and complicated logistics (Khalil et al., 2008).

In the developing countries, the composting of biowastes has not been an effective solution, which is one of the reasons of the generation of end-products that do not comply with quality standards (Hoornweg et al., 1999; OPS, 2005; Barreira et al., 2006; Kurian, 2007). The composting installations of small municipalities, which are herein defined arbitrarily as the ones with a population less than 12,000 residents, are characterized by resource limitations as well as by the fact that their operation is usually realized by operators that are not well trained and cannot perform complex activities (Turan et al., 2009; Shekdar, 2009; Marmolejo, 2011).

In such installations, the stability and maturity of the product is usually determined on-site with relatively easy to perform techniques, such as odor, color, temperature, humidity, pH and electrical conductivity (Ruggieri et al., 2008). These techniques can be inconsistent with laboratory tests used to assess stability and maturity. For example, typical on-site quality criteria can be to obtain a dry material, of a dark color, of a relatively small particle size and of an odor similar that to soil. However, physical, chemical and biological quality analyses at the laboratory can indicate if the product meets the conditions of stability and maturity (Zucconi et al., 1981; Icontec, 2003; Marmolejo, 2011; Cesaro et al., 2015).

The conditions of the operation of composting installations in small communities in developing countries are primarily governed by the lack of budget. On the other hand, there is a necessity to provide information on control schemes on the monitoring of the process and on the quality of the product. Based on the above, the primary objective of this work was to compare and correlate the results of the application of certain *laboratory* scale stability tests (volatile solids, C/N ratio, respirometric index, self-heating) and maturity tests (germination index) with some commonly employed *on-site* tests to assess stability (temperature, color, odor, moisture) and maturity (pH and electrical conductivity).

2. Materials and methods

2.1. Initial conditions and experimental setup

The study was developed in an actual biowaste composting installation in Colombia that accepts source separated wastes derived from the selective collection of biowaste. The separate collection of the biowastes takes place 2 times per week, and the amount of biowastes collected per day is between 1.3 and 1.5 t. The wastes used here were organic and almost exclusively of residential origin, since commercial activities are very low in the area under study. Approximately 90% of the population performs a separation of biowastes at the source. The dominant constituents in those biowastes (93% of the total wet weight) were non-processed food, such as plantains and tubers, citric and other fruit as well as vegetables and legumes. The remaining 7% were processed food, some paper and cardboard, pruning and garden waste and non-biodegradable material. The average temperature in the location is 18 °C and the average precipitation is 1500 mm/year. Monitoring of the quality of the biowastes that took place during the year showed that the raw material has a pH of 5.5 ± 0.5, a moisture content of 76.7 ± 3.2% (wet weight basis, wb), a TOC of 33.0 ± 4.8% (dry weight basis, db), a total nitrogen content (N_T) of 1.6 ± 0.5% (db), a C/N ratio of 21.7 ± 5.3 and an ash content of 25.1 ± 5.6% (db).

The study was based on the monitoring of 2 composting piles that were constructed by the generated biowastes during a period of 4 days (pile A1) and 3 days (A2). The piles were constructed approximately 24 h after the entrance of the biowastes into the composting facility and after the removal of non-biodegradable materials that normally takes place in the plant. During the formation of the piles, the material was manually homogenized and sieved through a 10 cm square mesh.

The 2 piles had, each, a weight of around 1400 kg, a conical shape and an average height of 1.1 m and were placed on an impermeable base and covered by a roof. A minimum distance of 3 m was kept between the piles. The piles were turned manually with shovels.

In order to monitor the temperature profile of the piles, the tip of a 70 cm thermometer was placed in the center of the piles to take daily temperature readings. The moisture content was attempted to be maintained always above 40% (wb) (Agnew and Leonard, 2003), until the initiation of the maturation phase (considered when the temperature rapidly decreased to around 30 ± 5 °C after approximately 60 days), by spraying tap water with a hose. On site moisture measurements were performed using a moisture analyzer (Ohaus MB-35). The turning of the piles was done to avoid the compaction of the material and when temperatures higher or equal to 65 °C were recorded. The monitoring of the process was done until the temperature of the piles approached ambient temperature (within a range of ±5 °C).

2.2. Stability and maturity tests

In this study, we used eleven (11) tests to determine the stability and maturity of the material. These tests were applied after the initiation of the cooling phase (maturation) until the end of the monitoring of the piles. Table 1 presents the stability and maturity tests that were applied in the laboratory as well as on-site. In addition, Table 1 includes the approximate capital cost of the necessary equipment used to perform these analyses. This is done in order to illustrate the cost differences between on-site (considered relatively cheap) and laboratory measurements (considered relatively expensive). When several alternatives are possible, the cost of each has been estimated.

For each measurement mentioned in Table 1, we followed the sampling protocols proposed by Sullivan and Miller (2001) which is based on the random collection of materials. Moisture was determined gravimetrically at 105 °C and the total organic carbon (TOC) was indirectly measured by the Walkley–Black method (Schulte, 1988; Sullivan and Miller, 2001; Icontec, 2003). pH and EC were measured on aquatic solutions prepared at a 5:1 (v/w) ratio utilizing, respectively, a pH meter (WTW™ Model 315i) and a conductivity meter (WTW™ model 325). Volatile solids were measured with the loss on ignition at 550 °C for 4 h. All above parameters were determined following the protocols established in the Colombian Technical Norm (NTC) 5167 (Icontec, 2003). Total N was measured according to the Kjeldahl method according to NTC 370 (Icontec, 1997). The germination tests were performed using radish seeds according to INN (2004), Varnero et al. (2007) and Komilis and Tziouvaras (2009). It is noted that radish seeds are considered an ideal choice for germination assays; actually, Komilis and Tziouvaras (2009) had observed that only the GI calculated by this type of seeds had a statistically significant negative correlation with certain stability indices. Extracts of 1:5 (g of wet material:mL distilled water) were prepared and after a 3 h contact time, the liquid phase was filtered and 10 mL of the filtrate were removed and placed in each Petri dish using 10 radish seeds placed on filter paper. The control contained only the seeds with distilled water. The Petri dishes were incubated at the laboratory at 25 °C. Duplicate measurements were performed. The germination index