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Biological recycling of used baby diapers in a small-scale composting system

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ABSTRACT

In Mexico used disposable diapers account for 6.5% of the urban waste that is sent to landfills, as no alternative treatment or valorization options is available. Due to their mixed organic–inorganic composition, they are usually perceived as a problematic non-biodegradable waste; nevertheless, due to their high cellulose content they could be recycled biologically in order to recover the nutrients present in them. This research assessed the feasibility of composting them along with yard waste, in 200 L bioreactors. An initial mixture of fresh trims of grass (55%), dry leaves (10%), fresh leaves (15%) and mulch (20%) was prepared and characterized to achieve an adequate C/N relationship. In the selected reactors 30% (mass basis) of previously shredded used baby diapers containing urine was added. The composting process lasted three months. Temperature, moisture, pH, nitrogen, CO_2 production, organic matter, C/N ratio, volume and mass reduction were measured and recorded periodically. The composting process was not affected by the presence of diapers. Temperature rose to 60–70 °C in the initial thermophilic phase, and reached a final plateau of 20–30 °C. The initial high temperatures allowed to eliminate the pathogens, as shown in the microbiological tests. Volume and mass of the substrates decreased more than 50% by the end of the process. Mass reduction for diapers was 87%, and only the plastic films were recovered. The final compost had good quality and accomplished with the limits set in the local regulation, except by pH, which has slightly above the set limit. It can be used as a soil amendment, as shown in the phytotoxicity tests performed using tomato. The results show that this is a feasible, affordable option for the valorization of used disposable diapers, which could be applied in small communities or daycare centers.

1. Introduction

Solid waste generation and management is an issue of big concern in modern societies. Developing countries face specific problems regarding it, due to social, educational and economic factors which do not allow application of state of the art technologies. Traditional waste management schemes, still used in many countries, are focused on confinement and landfilling; this strategy does not only use valuable land, but creates risk of dissemination of toxics in the environment. Waste recycling, on the other hand, promotes recovery of materials that can be used in new productive cycles, eliminating waste management requirements and saving natural resources. In Mexico more than 40,000 tons of wastes are generated yearly, with a high proportion of organic (38%) and potentially recyclable materials (40%) (Secretaría de Medio Ambiente y Recursos Naturales, 2012).

Used disposable diapers are one of the wastes whose composition and properties prevent straightforward valorization and recycling. The use of diapers has increased in Mexico in the last

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decades; in 1997, used diapers were the 6% of urban waste, now this amount has increased up to 15% in some areas (Instituto Nacional de Estadística y Geografía, 2010).

Diapers are used even in low income and rural areas. It has been determined that a baby can use up to 2190 diapers yearly (Procuraduría Federal del Consumidor, 2011). In Mexico, with a population of more than 5 million babies and toddlers between 0 and 2 years (INEGI, 2012), more than 32 million of diapers are sent to landfills every day. As a used diaper weights an average of 210 g (Puig and González, 2009), more than 6800 tons of diaper waste, which will not degrade easily, are disposed on a daily basis. Impacts associated to disposal of diapers landfilling include land use, methane production and leaching of organic compounds to soil and groundwater (Puig and González, 2009). Biodegradation of diapers in landfills is highly improbable, due to the fact that they're usually disposed of wrapped in its plastic layer, and to the lack of enough biological activity in landfills (Espinosa-Valdemar et al., 2011).

Different approaches have been tested to deal with this waste. Diapers can be incinerated along other organic wastes, but their combustion could lead to production of contaminants such as CO and chlorine compounds if not controlled properly (Riber, 2007); mechanical biological treatment has been applied to diapers in Spain, Italy and Germany (Archer and Whiting, 2005); costly mechanical separation and recycling has been tried in the US, Asia and Europe (Knowaste, 2009).

Diapers are perceived as a solid waste problem, nevertheless, they can also be treated as a valuable biodegradable resource that can be recovered. Diapers are made of a mixture of highly biodegradable cellulose, non-degradable plastic films and a super-absorbent polymer. Recycling of its organic content is an attractive option both, as a resource and waste management strategy. Anaerobic digestion has been applied in Canada and Belgium (Gellens et al., 1995; Forkes, 2007). Lab-scale composting has been tested in order to assess the feasibility of the process (Espinosa-Valdemar et al., 2003), and the fate of the super-absorbent polymer and pathogens (Stegmann et al., 1993; Cook et al., 1997; Gerba et al., 1995). Recently, integral full-scale projects have been developed to assess the biodegradability of compostable diapers (Colón et al., 2013) and the effect of introducing diapers in the humus obtained in the process (Colón et al., 2010). Also, biodegradation of diapers by the fungus *Pleurotus ostreatus* has been assessed as a way to recover their organic content and decrease the volume of waste to be disposed (Espinosa-Valdemar et al., 2011).

Nevertheless, in third world countries there is a lack of affordable technologies which can be implemented in integrated waste management systems, especially in small communities which lack basic infrastructure. In this context, the purpose of this research is to test the feasibility of composting used disposable baby diapers along with yard waste, in order to design a modular, scalable, easy to operate system which would allow valorization of the cellulose and decrease of waste management needs.

2. Materials and methods

In order to test the feasibility of composting used disposable baby diapers, these were composted using bioreactors along with yard waste. The resulting compost was tested for possible phytotoxic effects toward a selected plant species. The research design is shown in Fig. 1.

2.1. Materials

Used baby disposable diapers containing urine, from babies between 0 and 2 years old, were collected in public daycare centers located in municipalities of the Estado de México and in the north sector of México City. Urine containing-diapers comprise 2/3 of the used diapers produced, and have less risk of spreading pathogens than those containing feces. Diapers were kept at 4 °C until they were ground in a Vermeer BC 1000 mill, where they were cut into 5 cm × 5 cm pieces.

Yard waste was obtained from the gardening activities of the Universidad Autónoma Metropolitana-Azcapotzalco, where up to one ton of yard waste is produced every week. Grass, dry and fresh leaves were used directly, while mulch was obtained by shredding of branches and bark. Diapers and yard waste were characterized using national standards by measurement of pH (NMX-AA-025-1984), total nitrogen (Férnandez Linares et al., 2006), organic matter (Espinosa-Valdemar, 2010), humidity (NMX-AA-016-1984), ashes content (NMX-AA-018-1984) and C/N ratio (NMX-AA-067-1985). Based on such information a 600 L mixture containing grass (55 wt.%) dry leaves (10 wt.%), fresh leaves (15 wt.%) and mulch (20 wt.%) was prepared. This substrate was divided in two and one half was mixed with shredded used disposable diapers in a 70:30 mass ratio.

2.2. Composting process

After mixing, the waste was introduced in four drilled bioreactors (200 L each), made of high density polyethylene. Two reactors were filled with the diaper–yard waste mixture, and the other two, used as controls, contained only yard waste prepared as described in Section 2.1. The waste mixture placed in every bioreactor was mixed with a shovel, in order to make the substrate homogeneous and to guarantee appropriate oxygen levels. This was done daily during the first two weeks, every other day in weeks three to five, and weekly afterwards. Mass (measured in a CAMESA scale with a 500 ± 0.2 kg capacity) and volume of the substrate in each bioreactor were recorded weekly.

Both composting processes were monitored by recording temperature, pH, moisture content and CO_2 production at the beginning of the test, after the first week and every two weeks afterwards until the end of the experiment, which lasted three months. Temperature was measured with a TFA stem thermometer (−10 to 90 °C), pH was determined with a potentiometer and moisture content was measured with a Lincoln soil moisture stem meter (with 0–100% range). A Vernier sensor was used in order to measure CO_2 production.

At the end of the test the resulting compost was sieved in order to recover any plastic and remaining cellulose from the diapers. C/N ratio, total and fecal coliforms (NOM-004-SEMARNAT-2002) were measured as a safety parameter against risks to public health. Finally, the quality of the compost was verified against the local standard PROY-NADF-020-AMBT-2011, which sets the minimum requirements for composting process of organic waste in Mexico City.

2.3. Phytotoxicity test

The resulting compost was tested to verify its quality as a soil amendment and to assess any possible negative effect on plant growth following the guide OCDE 208 (Organization for Economic Co-operation and Development, 2006). Tomato (*Lycopersicon esculentum*) seeds were obtained from Distribuidora Rancho Los Molinos S. A. de C. V., and tested to assess their viability. Tomato was selected as a model given its national relevance. It is grown throughout the year in Mexico. The country is the second largest exporter of tomato worldwide. This species constitutes 37% of all vegetable exports to the country (Secretaría de Agricultura, 2010). Twenty seeds were set on a cotton pad in a Petri dish, and 20 ml of water were added. Five replicates were prepared, all the boxes