Journal of Environmental Protection, 2012, 3, 298-303
http://dx.doi.org/10.4236/jep.2012.34038 Published Online April 2012 (http://www.SciRP.org/journal/jep)

Biodrying under Greenhouse Conditions as Pretreatment for Horticultural Waste

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Received February 2nd, 2012; revised February 29th, 2012; accepted March 31st, 2012

ABSTRACT

The biodrying process was studied as an alternative technology to reduce the mass and volume of horticultural waste. Four static piles were prepared inside a greenhouse: two containing whole waste and two consisting of shredded waste. All the piles were compared with a test pile containing whole waste and placed outside the greenhouse. In two cases, ventilation ducts were installed to improve aeration. Each greenhouse was 2.0 m wide, 3.5 m long and 1.16 m high. The air temperature and relative humidity were monitored both inside and outside the greenhouse. Mass, humidity, organic matter and total nitrogen in the waste were measured. Piles inside the greenhouse showed decreases of 80% and 75% in weight and volume, respectively, during the first 16 days. The data obtained in this work suggest that biodrying could improve the handling and transport of horticultural waste while also minimizing the impact of pollutants.

Keywords: Solid Waste; Aerobic Degradation; Stabilization; Greenhouse

1. Introduction

Nowadays, there are more than 60 distribution centers of fresh food products ("Centrales de Abasto") operating in Mexico. Together, they produce thousands of tons of horticultural waste every day, which rots easily because it is organic matter and has high water content. The biggest distribution center of fresh food in Mexico City generates close to 585 tons of damaged and spoiled fruits, vegetables and flowers daily. Most of this waste is disposed of in landfills without any kind of pretreatment or recovery process [1].

Horticultural waste can be treated by an aerobic process like composting or biodrying. Biodrying, which is a fairly recent development in the field of waste management, is a treatment that uses forced aeration along with the heat generated by natural aerobic bioconversion of some organic matter to dry the waste. Most of the biological heat produced is utilized to evaporate surface and bound water associated with the waste matrix.

The most obvious advantage of biodrying is the reduction in odor, volume, and weight of the waste, which in turn may improve handling, transport and disposal of organic waste when a high volume of waste is an issue. Furthermore, biodrying has also been proposed as an effective means of eliminating some pathogens [2].

As reported previously [3], a controlled air supply can be used to increase the drying rate, which in turn increases the rate of water evaporation. However, the velocity and temperature of the air must be controlled adequately, because the aim of biodrying is to achieve satisfactory water loss in order to obtain a homogeneous, stable and useful product [4]. Biodrying is typically carried out in tunnels or biological reactors, where air is supplied and the ideal conditions of temperature and humidity are maintained to ensure a balance between the drying rate and the aerobic degradation of the organic matter [4-6].

Currently, most studies dealing with the biodrying process focus on reducing the water content of municipal solid waste while preserving its calorific power, in order to obtain a refuse-derived fuel [4,6-8]. Other applications of biodrying have also been researched; for instance, Navaee-Ardeh *et al.* [9] reported that biodrying is an attractive technique for drying sludge from the paper industry.

In the last few decades, a number of researchers have studied the production and collection of biothermal en-

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ergy obtained from compost of different kind of organic wastes, to be used in growing plants in greenhouses [10], in heating bedrooms in home [11,12]. Conversely and according to the open literature, no reports have been published on the potential use of the heat of greenhouses, as an efficient collector of solar energy, to improve biodrying of horticultural waste. Thus, in this work, the biodrying process, conducted under both environmental and greenhouse conditions, was studied to evaluate whether it can be considered as an alternative to reduce the mass of horticultural waste in a short period of time in order to enhance handling, transportation and final disposal capacities.

2. Material and Methods

2.1. Feedstock Characteristics

The horticultural waste feedstock was sampled from the biggest market of fresh food products in Mexico City, the "Central de Abasto de la Ciudad de México". It consisted of a mixture of different kinds of vegetable waste, lettuce being the most common product. The trials were performed in small greenhouses constructed as shown in **Figure 1**. Each greenhouse was 2.0 m wide, 3.5 m long and 1.16 m high and was based on a metallic framework. This metal structure of the greenhouse was covered with a white long-life polyethylene film with a thickness of 180 microns. In order to improve the biodrying process, the front and the back of the polyethylene film were removed daily for one hour. In order to provide oxygen and allow air to penetrate and move through the pile by passive convection and diffusion, ventilation ducts were placed in some of the piles as indicated in **Table 1**; the size of the ducts were 0.25 m high and 2.5 m long.

2.2. Sampling Locations

Five static biodrying piles containing between 221 and 325 kg of horticultural waste were prepared as shown in **Table 1**. Air temperature and relative humidity were monitored inside and outside the greenhouse. Pile temperature was measured with a long-stemmed thermometer both in the center (approximately 15 cm below the surface) and in the peripheral zone, and data were recorded daily for 35 days. Samples of 10 g of horticultural waste were taken from the center of the piles and used to evaluate water, organic matter and nitrogen contents.

2.3. Measured Parameters and Measurement Methods

Mass loss, humidity, organic matter and total nitrogen in the waste were measured. Moisture and dry matter content were determined daily by a gravimetric method in compliance with the Mexican standard procedure established by NMX-AA-16-1984 [13]. Briefly, samples weighing between 3 and 5 g were put in an oven at 60˚C (CR1-2 Shel Lab Cleanroom Oven) for about 2 hours and allowed to cool to room temperature in desiccators. They

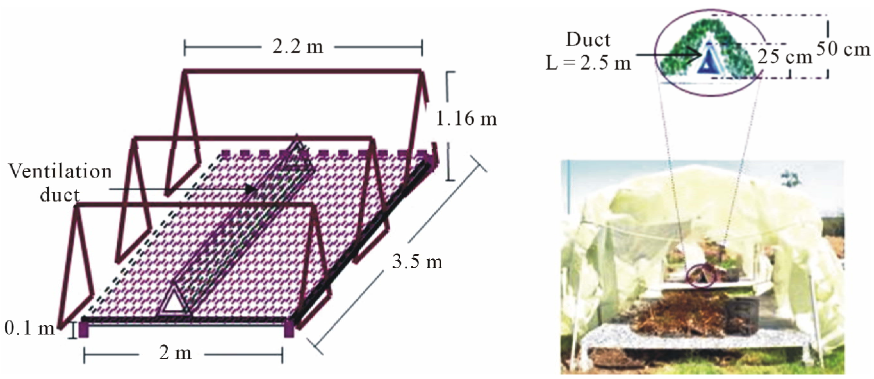

Figure 1. Experimental setup.

Table 1. Operational conditions of biodrying assays.

Pile	Initial mass (kg)	Characteristics (Waste integrity/Ventilation/Surroundings)
1	284.5	Whole waste/ventilation duct/in greenhouse
2	221.1	Shredded waste/ventilation duct/in greenhouse
3	324.8	Whole waste/no ventilation duct/in greenhouse
4	254.5	Shredded waste/no ventilation duct/in greenhouse
5	279.6	Whole waste/no ventilation duct/under environmental conditions

were then weighed and heated again for about 2 hours, after which the sample was cooled and weighed a second time. The procedure was repeated until the weight difference between two successive operations was less than 0.01%.

Total Nitrogen was measured by the Kjeldahl method on wet material [14]. Organic matter was quantified, in accordance with the Mexican standard procedure [15], by applying the Watley-Black colorimetric method. Briefly, three 0.1 g samples of horticultural waste were treated with 0.1 N potassium dichromate (99.9% pure, J. T. Baker) as a strong oxidizing agent in sulfuric acid (98% pure, Reasol). The mixture was swirled vigorously for 1 minute and allowed to stand on a heat proof surface for 30 min to allow oxidation of the organic matter to proceed. Distilled water and phosphoric acid (95% pure, Reasol) and diphenylamine (J. T. Baker) were then added as an indicator solution. When the reaction was completed, unreacted dichromate was titrated by adding 0.5 N ferrous sulfate (J. T. Baker).

3. Results and Discussion

3.1. Evolution of Weight and Water Content during Biodrying

Based on the results presented in **Figure 2**, it was estimated that in the first two days, whole and shredded waste lost 15% and 20% of their water content, respecttively, as leachate. This rapid loss of water during this short period was due to lixiviation by hydrolytic decomposition as a result of partial degradation of the organic matter, since water in horticultural waste can be released as leachate when the wall or membrane cells are degraded, as reported previously [16]. Next, the heat generated in the pile as a by-product of the microbial breakdown of organic material acts as the energy for evaporation. As in composting, in biodrying most of the energy released during microbial activity is used to evaporate water from the waste materials. Then, following the hydrolytic stage, evaporation helped to diminish water content in the horticultural waste; consequently, the weight of the waste had diminished by 82% in the four piles inside the greenhouse on day 16. Nevertheless, the weight reduction observed in the control pile was only 22% over the same period of time, compared with the initial weight.

Our results showed that while drying, waste did not lose water at a constant rate and the rate of water removal under fixed conditions dropped off as drying progressed. At the beginning of biodrying and for some time thereafter, water generally continued to be lost from the waste at a constant rate. This was followed by an inflection in the drying curve, which leads to the period in which the drying rate drops [17]. During the initial period of the drying

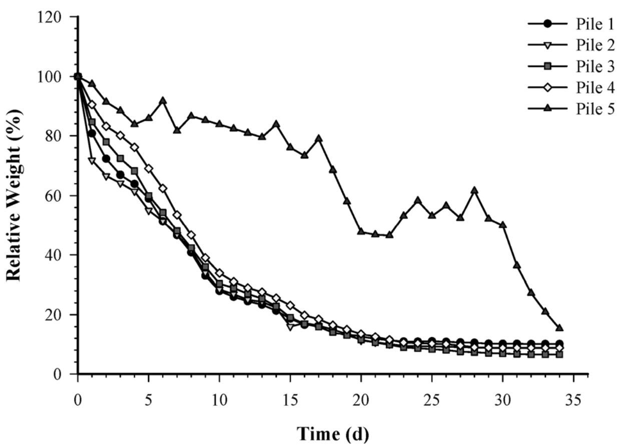

Figure 2. Weight loss of horticultural solid waste during biodrying.

process (constant velocity), the heat is transferred to the product and to the contained moisture.

In the next phase of the drying process, free moisture persists on the surfaces and the rate of evaporation alters very little as the moisture content is reduced. There is a gradual and relatively small increase in the product temperature during this period [18]. Initial water content was 95%. According to results, it could be inferred that for all the piles inside the greenhouse, waste humidity is reduced at two drying rates: 1) the constant rate of drying, where the fastest decrease in waste humidity (from 95% to 18%) was attained in a short time (16 days); and 2) the falling rate of drying, where more time (19 days) was required to remove another 9% from the remaining water (from 18% to 9%). The weight loss curve of the piles in the greenhouse became asymptotic on day 24, which means that the material reached the equilibrium state with the surroundings. Thus, zero moisture content was never achieved, which is a similar behavior to that reported by N. K. Thakur and N. S. Thakur [17]. In the control pile, the maximum decrease was reached at the end of the experiment (35 days). The reason for this is that the control pile was often re-humidified by rain and condensing phenomena at dawn, above all on rainy days (days 5 and 21), since this pile was kept under outdoor conditions.

3.2. Loss of Organic Matter during Biodrying

During biodrying, weight loss results from a reduction in water content and, to a lesser extent, from partial degradation of organic matter. As depicted in **Figure 3**, during the first 16 days the organic matter content was reduced from 80% to 50%, which coincides with the period of high microbial activity. The rest of the time the reduction was lower (from 50% to 38%). In the control pile, a bigger reduction was observed in the organic matter content (from 80% to 20%) because the pile was constantly

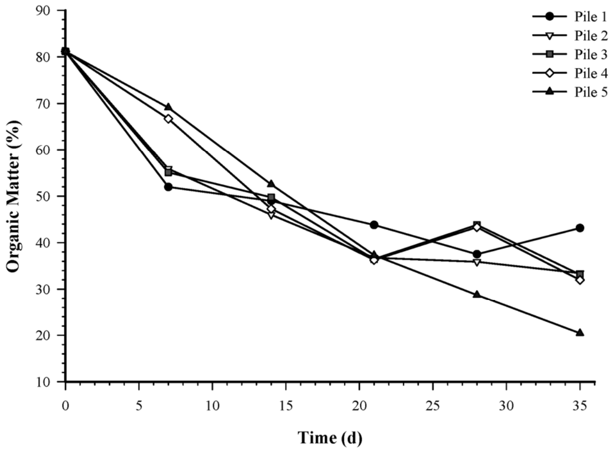

Figure 3. Reduction of organic matter during biodrying.

re-humidified (by the rain), thus allowing the microbial activity to continue throughout the experiment.

3.3. Influence of Climate on Biodrying

Due to changes of climate, the air and waste temperatures inside the greenhouse varied during the experiment. Since all the piles in the greenhouse behaved in a similar manner (**Figure 2**), pile 1 was taken as being representative of all of them. The changes in solid waste, together with indoor and outdoor air temperatures are shown in **Figures 4** and **5**. The highest temperatures of waste inside the greenhouse were observed during the first three days, when they exceeded the greenhouse temperature (**Figure 4**). In this period, microbial activity was more intense. The lowest greenhouse temperatures (17˚C) were found on days 5 and 6, when the environmental temperature descended to 10.4˚C, which affected the waste temperature and therefore the performance of the process. After that time, waste temperature increased again but never exceeded the air temperature inside the greenhouse, although most of the time it was higher than the environmental temperature.

There was a variable difference in temperature (ΔT) from day 1 to day 15, between the inner and outer layers of the waste piles inside the greenhouse. This suggests that the biodrying process ends on day 16 (case of pile 1) when the surface and center pile temperatures became equal (**Figure 5**).

3.4. Advantages of Biodrying in Greenhouse

The drying process in a greenhouse results in two main effects:

1) Generation of metabolic heat due to the aerobic microbial activity in the waste. Such a metabolic effect is responsible for the process called biodrying, as stated by some authors [6,7]. As a consequence of heat generated by the intense microbial degradation, the waste temperature was higher than the greenhouse temperature during the first three days and on the sixth day (**Figure 4**).

Biodrying piles reached temperatures between 29˚C and 37˚C during the first four days. The thermophilic phase (above 45˚C) was not reached because of the low volume of the piles, and the water content was excessively high. In this case the heat derived from the biodegradation was not enough for water evaporation, as suggested by Zhang *et al*. [16].

2) Solar energy stored as heat inside the green house that helped to increase mainly the air temperature but also to a lesser extent the waste temperature. On the other hand, the temperature and relative humidity, both of which were higher in the greenhouse than in outdoor conditions, could have a positive effect on microorganisms in waste by improving microbial growth and activeity, mainly in the case of fungi. In addition, the greenhouse protected the piles from the rain, thereby preventing the horticultural waste from being re-humidified.

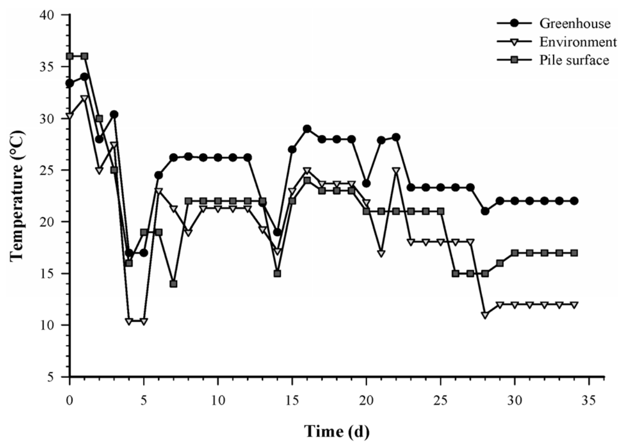

Figure 4. Temperature behavior in greenhouse, environment and pile surface.

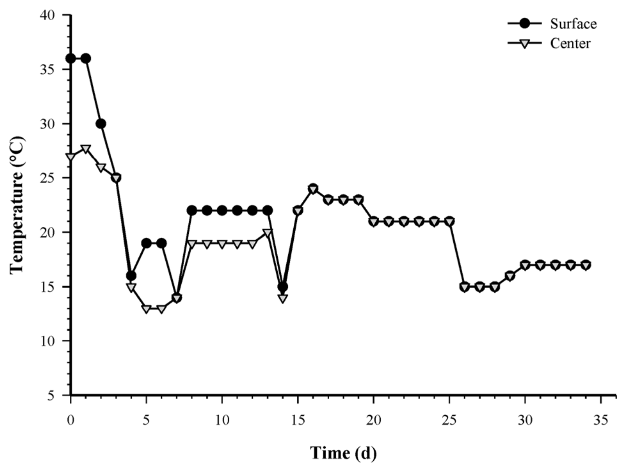

Figure 5. Evolution of internal and surface temperatures of solid waste.

3.5. Physicochemical Characteristics of Biodried Horticultural Waste

The physicochemical characteristics of horticultural waste before and after the biodrying process are shown in **Table 2**.

The initial humidity of the horticultural waste at the beginning of the process was 95.5%, while at the end of the process it was between 3% and 6%. Such a large reduction in humidity and partial biodegradation of organic matter resulted in a mass reduction above 90% at the end of the process (35 days). Considering that the biodried horticultural waste was partially stabilized, it is possible to infer that the material could be used as organic amendments for soils. Further work is needed to evaluate the influence of this material in crops.

4. Conclusion

The final weight, volume and humidity values achieved in this work allow us to suggest biodrying as a pretreatment of horticultural waste in order to improve the capacity for handling, transportation and final disposal of horticultural waste without giving rise to pollution problems. The novelty of carrying out the biodrying process in a greenhouse lies in the fact that the heat of the enclosure and the energy resulting from microbial activity in horticultural waste raise the efficiency of the performance of water removal and water content reduction in waste. Biodrying in greenhouses could be proposed as a technology to stabilize waste with high water content, like the refuse produced by important fresh food markets. Nevertheless, since air moving through the compost pile (either by forced ventilation or passive convection and diffusion) gets hot and evaporates water from the surfaces of particles, further work is needed to evaluate the influence of forced airflow on biodrying kinetics in a greenhouse and performance in piles with a larger volume. Such work will make it possible to lower the time needed to reach target moisture contents and to evaluate whether thermophilic temperatures could be achieved during the processes.

Table 2. Physicochemical parameters of waste during biodrying.

Parameter	Piles in greenhouse		Control pile	
	Initial value (%)	*Final value* (%)	*Initial value* (%)	*Final value* (%)
Humidity	95.48	3 - 6	95.48	14.6
Volume	100	25	100	42
Mass	100	5 - 9	100	18
Organic Matter	81.16	40	81.16	20
N content	1.99	1.25 - 1.75	1.99	1.25

5. Acknowledgements

The authors acknowledge financial support from the Instituto Politécnico Nacional (SIP and COFAA). We particularly wish to thank Ricardo Estrada Núñez from the Mexico City Government (DGSU) and Rogelio Bailón Morales from the IPN compost plant in Mexico.

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