Windrow Composting of Agricultural Residues
NRCS-CIG 69-3 A75-9-163
Final Report

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Introduction

Agricultural residues in Puerto Rico have not been considered as a manageable resource, but a waste byproduct. This consideration is the result of the lack of understanding of the techniques to properly recycle these byproducts. When properly composted these become beneficial stable products that can be used or sold for additional farm income, which can provide a stable nutrient source. It has been shown that composted coffee pulp can have 4.9% total nitrogen, 0.3% phosphorous, and 3.0 % potassium (Chong and Dumas, 2012). One method that can be employed to process large and diverse amounts of agricultural residues is the Windrow Composting (WC) method. This method employs the arrangement of organic materials to be composted in large long piles, where with the implementation of a tractor and a specially design adapter the piles are periodically turned to allow air to enter the pile and facilitate the composting as the tractor moves alongside the pile (front cover picture). This method easily handles large amounts compostable of materials, being restricted by the composting field. Other methods like aerated static piles or within-vessel composting are space limited and require a physical structure such as a building or vessel for the compost material. The Puerto Rican coffee industry produced an estimated 20,218 tons of coffee byproduct residues for the 2011 coffee season[1].

Windrow composting offers the possibility of composting large quantities of organic wastes that can be managed with relatively low operational cost and low energy consumption when compared with other composting methods such as in-vessel or aerated static pile methods (Diaz et al., 2002; van Haaren, 2009). Other studies have pointed out windrow composting to be more feasible than static aerated system assuring adequate aeration and final compost quality (Diaz et al., 2002). Specialized windrow turners have being pointed out to produce better quality compost in comparison to front-end loaders (Nelson, 2010) minimizing the turning time and assuring a fine compost texture.

Windrow Composting Area with Constructed Wetland

Discussed is a windrow composting and water management design system to manage agricultural residues adapted to the humid tropical conditions of Puerto Rico. Compost windrow piles are covered at all times, except when these a turned to avoid any rain that that could cause nutrient runoff. The cloth cover is specially designed to allow CO_2 to escape, O_2 to come into the pile and exclude water (Figure 2). In addition a sediment trap is set prior to a wetland where the final storm water gets treated with aquatic plants. The constructed wetland mimics natural ecosystems and provides a natural

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[1] Tonnage is estimated from production assuming a 77% of the grain by weight basis.

treatment for the polluted water. The wetland is potentially able to treat water against chemical pollutants, pathogens and particulate matter present in the water.

The compost area consists of 11,900 1ft^2 plot (85 x 140 ft.) with capacity for 4 compost windrows (Figure 1). Each windrow potentially is 140 ft long, 9 feet wide and 4 ft high, this provides a volume capacity of 10,080 ft^3. The compost area has 4 access corridors that allow tractor movement and windrow management with a slight down gradient to lead the rainfall water in the compost area toward the wetland by gravity (Figure 1). A 6 inch pipe connects the compost area to a sediment trap and then to the constructed wetland. The sediment trap box (Image 1) allows the mechanical removal of the sediments with the front-end loader of the tractor. Sediments collected on the trap box are re-incorporated into non-mature compost piles. The wetland consists of a 2 ft wide channel creating a serpentine, that forces water though the channel, maximizing the wetland area in a relatively small space. The wetland outlet consists of a swivel elbow connected to the bottom of the end of the serpentine channel that allows the control the water level in the wetland. To keep wetland water level and avoid ground water contamination, the wetland should be impermeable. To achieve this, a plastic liner was placed to serve as an impermeable barrier against wetland leaching. If the soil or the site substrate allows it, this could be also achieved by compaction and by adding sodium

Image 1. Sediment trap box.

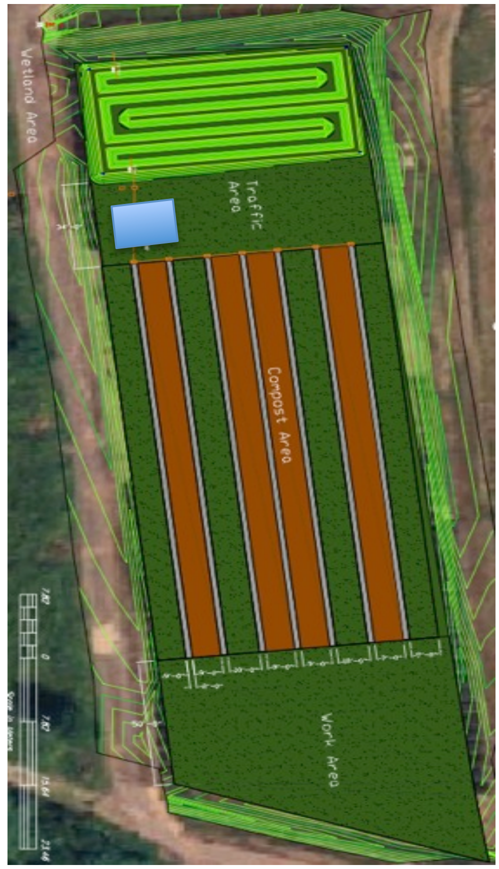


Figure 1. Upper view of representative diagram of composting project including composting area (brown), sediment trap (blue) and wetland

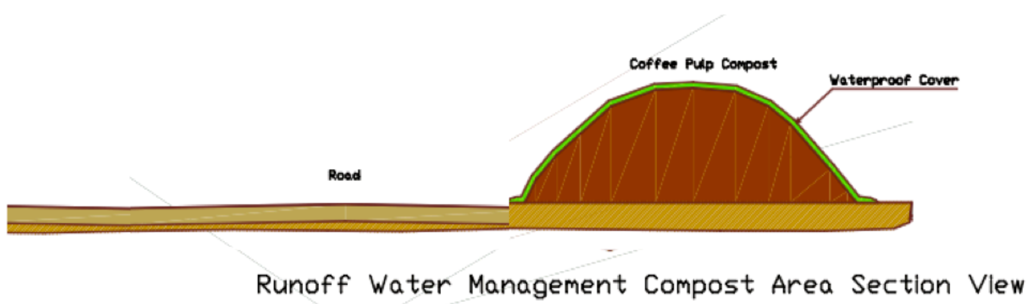


Figure 2. Cross section of elements in composting area

to the soil to disperse soil particles and seal the surface to water percolation. Additionally a floodgate was constructed on a wetland sidewall to facilitate the complete drainage and cleaning of the sediment buildup if needed.

Wetland plants play an important role for biological water remediation. The plant roots absorb nutrients, but also provide the ecological conditions for the development of microorganisms. We currently use Water Hyacinth (*Eichhornia crassipes*) as it is a strong plant that lives with little water during the dry season. These have provided to be adaptable, fast reproducing rate and tolerant to high nutrient loads. Water hyacinth (Image 2) has a high reproduction rate and tends to dominate over any other wetland plant we tested, such as water lettuce and Azolla. When cleaning the wetland or when overgrown or excess hyacinth plants were present these were removed and composted in the windrow piles.

Image 2. Water hyacinth

Wetland Effectiveness

Wetland effectiveness in removing nutrient loads was observed by measuring nutrient, oxygen and pH difference between inlet and outlet water. Nutrient removal by the aquatic plants was efficient as shown the values of water analyses at the entrance and exit of the wetland, before it was discharged through the swivel elbow (Figure 3). Removal of phosphorus and nitrogen was above 90 and 75 percent, respectively, which indicates an efficient system for treatment of the wastewater of this composting facility.

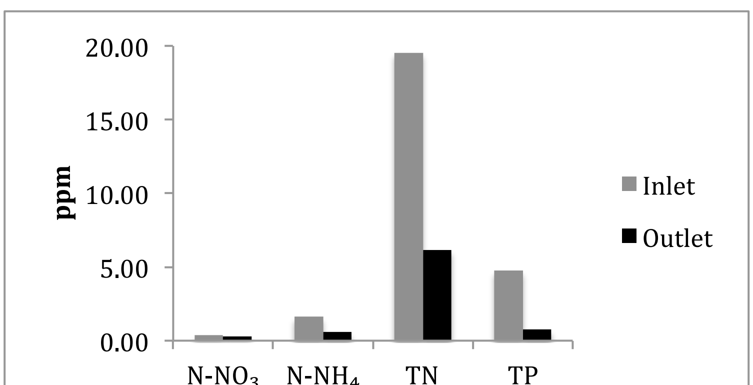


Figure 3. Nutrient concentration in the inlet and outlet of the constructed wetland

Dissolved oxygen (DO) concentration was 7 times higher in the outlet section than in the inlet section (Table 1) and in general DO was above the Environmental Protection Board requirements for rivers and lakes, which is at least 5% dissolved oxygen. The water pH was not significantly changed ranged from 6.6 to 7. This data confirm the above-mentioned results, which indicate the good quality of the water discharged through the swivel elbow. However, data in Table 2 suggest must be taken provisions to avoid discharges that exceed the system processing capacity.

	pH	Dissolved Oxygen (%)
Inlet	7.0a	4.96 b
Outlet	6.6a	35.02a

Table 1. Results of pH and dissolved oxygen of constructed wetland.

	pH		Dissolved Oxygen (%)	
	(Inlet)	(Outlet)	(Inlet)	(Outlet)
Jun/05/2012	6.15	6.12	5.8	32.9
Jun/15/2012	6.21	5.72	2.1	9.1
Jun/22/2012	7.79	6.17	1.1	70.2
Jun/29/2012	7.80	6.99	2.5	68.3
Jul/06/2012[2]	7.14	6.80	1.2	1.9
Jul/20/2012	7.67	7.74	0.6	0.5
Aug/03/2012	6.90	6.55	5.1	10.8
Aug/10/2012	6.99	6.68	21.3	47.2
Aug/17/2012	6.94	6.70	33.4	75.9

Table 2. pH and dissolved oxygen throughout all the sampling dates.

[2] Reflected here the excess of carring capacity of the system as afected by anaerobic material as described below.

Windrow Composting Process

The windrow-composting project at Adjuntas Experiment Station is mostly supplied with coffee pulp from various coffee processing plants but it also has received chicken manure and orange peels from an orange processing plant. Coffee pulp quality greatly influences the composting process and the end product quality. Coffee pulp quality for compost refers to freshness, and moisture content prior to arrival decomposition. Difference in pulp quality differs from processing plant to processing plant, due its management after seed removal. Some processors ship their coffee pulp quickly after processing, which provides us with fresh composting material. Other processing plants accumulate the coffee pulp in large ponds for months undergoing anaerobic decomposition. When this material is received it accumulates lixiviates and water and it is of a dense macerated consistency. This particularity has implications in the management of the waste during composting process, as further explained, but also it has environmental implications.

Image 3. Death of water hyacinths because of low quality coffee pulp runoff.

Material that has been anaerobic under water for a long period requires special handling when it is received. On July 5, 2012 a poor quality compost batch (≈150 m^3) was brought to the composting facility. Poor coordination and mitigation of the material caused water lixiviates to enter and kill the wetland water hyacinths, disabling the wetland remediating water capacity (Table 2, Image 3). The material was for more than six months under water anaerobic conditions and had lost its pulp structure. As seen in Table 2 the only dates in which the levels of dissolved oxygen do not fulfill Environmental Protection Board requirements (5% Dissolved Oxygen) corresponded to the arrive of the coffee pulp shipment of very poor quality. Although the wetland eventually was able to overcome this situation it struggle as shown in the dissolved oxygen status.

The composting site needs to be prepared to receive material that has been anaerobic and underwater for a long period of time. This material is characterized for the lack of coffee pulp structure, odor and high density that makes the material impossible to turn with the windrow implement. The preparation is as follow: Existing compost is placed horizontally to the slope of the wetland to absorb the material water and block any passage of liquids into the wetland. This needs to be coordinated in regards to the amount of material to be received. After a day of dewatering, the material is mixed with the compost adding compost until it looses its density and is manageable without leaching any liquids. The receiving of this material needs to be coordinated not to go above the carrying capacity of the composting site.

Ideally all feedstock should be treated appropriately so it does not become an environmental problem. Conversations have taken place to alleviate this problem at the processing site.

Equipment

The Adjuntas windrow composting project has an Aeromaster PT-120 pull type-windrow turner pulled by a McCormick C105 max 99hp tractor (Image 4). This windrow turner manufacturing specs detail it could manage a production of around 10,000 tons of finished compost per season and process approximately 1,000 cubic meters per hour. Trucked coffee pulp is set on the ground and piled up with a front-end loader to form the initial windrow pile. This windrow turner model produces compost windrows of around 9 ft base wide and 4 ft height about 140 ft long.

The management that receives the coffee pulp once it gets to the premises depends on its quality. If the coffee pulp is relatively fresh and dry the compost could be made with 100% coffee pulp. If the coffee pulp is macerated and too wet due to previous partial anaerobic decomposition three options can be made 1) left to dewater for a week or two, 2) mix the pulp with wood chips a rate of 2 parts coffee pulp and 1 wood chip or preferably 3) the material is mixed with composted material. Compost used as bulking agent enhances microbial activity, increases compost speed as it structures and dries too wet coffee pulp making aeration and equipment use easier.

Coffee pulp has 80-90% intercellular water content, in contrast with other feedstock material that require the constant addition of water, coffee pulp rarely requires watering due to its initial high water content. However once piles reaches $\leq$ 100°F, piles can be inoculated with microorganisms to speed and gear the final curating process. The management of other waste with lower water content could require periodical additions of water in order to maintain an optimal microbial activity. We have also used orange peels and chicken manures effectively as add on to the coffee pulp compost with no detrimental effects.

Image 4. Aeromaster PT-120 pull type-windrow turner pulled by a McCormick C105 max 99hp tractor

Turning frequency and the joining of windrow piles

Coffee pulp is turned daily during the initial two-three weeks depending on its water content and temperature. Daily temperature monitoring allows us to make management decisions on the processing of the compost piles. We measure temperatures at each compost pile at three depths within the pile. A three-foot long thermometer is inserted on top of the pile to reach the lower center part until just an inch of the head is above the compost. The measured temperature at this depth is the center of the pile. Then the thermometer is removed about 12” and another 10-12” where mid pile temperature and superficial temperatures are recorded. The difference between the inside, mid and superficial temperatures are used to evaluate compost pile turning ratios and the joining of piles. Lower temperatures inside when compared to outside temperatures indicate the need to turn the pile. Little differences between the inside, mid and outside temperatures indicate proper composting or the finalizing of the composting process.

A video description on the use of temperature to monitor the compost pile can be seen here:

http://youtu.be/ORLLvdEl9eU

compostapr ›

Temperatura tu aliado en la composta!

Created: Mar 28, 2013 • Duration: 6:22 • Lifetime views: 1,556

VIDEO

Lifetime (Mar 28, 2013 – Feb 8, 2014)

Here are the top five countries and its video count in which this video is seen:

Geography	Views
Mexico	437 (28%)
Puerto Rico	356 (23%)
United States	191 (12%)
Spain	186 (12%)
Argentina	56 (3.6%)

Temperatures are used to decide which piles are mixed together. When a pile needs to compost better, it is known due to lower temperatures, it could be mixed with a pile that his running hot, or this could also be done by proximity to ease work. Once compost thermophilic phase is over, temperatures less than 100°F, the compost pile is allowed to enter its curing second phase and turning is kept to a minimum, once weekly or once every other week.

Another feature that regulates composting conditions and controls leaching during rains are the compost covers (Toptex Compost Protection Fleece). The covers (Figure 2, Image 5) are made from polypropylene fibers and are impermeable to water but permeable for gases exchange. These covers are only removed to turn de windrows and are put in place again right after the piles are turned. These covers not just prevent excessive leaching but also help to keep moisture during hot and dry periods. These covers also protect biological activity from the harmful effect of solar radiation. These covers could be used also to store finished compost in the outdoor.

Image 5. Cover used to protect compost windrows against leaching during heavy rains.

Carbon Sequestration

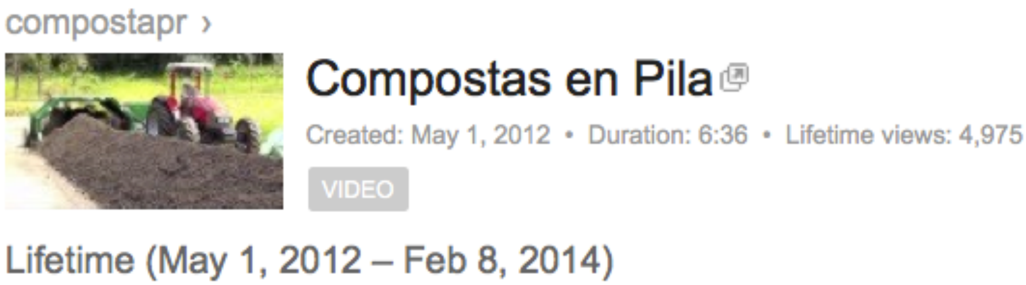
Humic acids are considered long term highly stabilized organic matter resistant to decomposition. Based on the carbon sequestration potential of compost through the formation of humic acids we can calculate-estimate carbon sequestration. Chong and Dumas 2012 reported an organic carbon content of humic acids of 31.4 g/kg from coffee pulp compost. The total compost produced thought out the project 2010-2013 accumulated a total of 1059 tons (1630 wet tons). Based on the humic acid concentration of compost considered to be long term stable this is equivalent to 33.3. This is a total of 33.3 metric tons of CO_2 sequestration for the period of 2010-2013 coffee production seasons.

Total quantity of feedstock brought to compost site per coffee production season	Tons of wet feedstock	Tons left after compost calculated at a 65% of the total[3].	Estimated CO_2 sequestration (tons)
TOTAL 2010-11	333	216	6.8
TOTAL 2011-12	838	545	17.1
TOTAL 2012-13	459	298	9.4
Grand Total	**1630**	**1059**	**33.3**

[3] Reduction reflects the evaporation of water, the oxidation of organic matter into more stable compost.

Here is an additional video describing the windrow composting facility during one of the outreach activities:

https://www.youtube.com/watch?v=4VC7X9RGEbs



The video top five countries views are as follow:

Geography	Views
Mexico	1,181 (24%)
Spain	937 (19%)
Puerto Rico	575 (12%)
United States	471 (9.5%)
Colombia	256 (5.1%)

Literature Cited

Chong, J.A. and J.A.Dumas. 2012. Coffee Pulp Compost: Chemical Properties and Distribution of Humic Substances. J. Agric. Univ. P.R. 96(1-2): 77-87.

Díaz, M.J., E., Madejón, F., López, R., López, and F., Cabrera. 2002. Composting of vinasse and cotton gin waste by using two different systems. Resources, Conservation and Recycling 34:235–248.

van Haaren, R., 2009. Large Scale Aerobic Composting of Source Separated Organic Wastes: A Comparative Study of Environmental Impacts, Costs, and Contextual Effects. MS Thesis, Columbia University, Unpublished Results.

Nelson, V., 2010. Assessment of Windrow Turners, Agtech Centre. <http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/eng9938> (Last accessed March 2010).