Turning Waste into Resources: Developing an Integrated Organic Waste Management System in Monteverde

An Interactive Qualifying Project Report submitted to the Faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science

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Abstract

Our team worked with Vision to Reality, a private company focused on tackling social and environmental challenges in Monteverde. The goal of the project was to improve Monteverde’s waste management by designing a system that converts organic waste into sustainable resources. We performed in-depth research of the processes within the waste management system to better understand the treatment methods. Upon arrival, we interviewed experts to assess the current state of organic waste disposal. Based upon the findings of the interviews, we composed preliminary designs for systems, built small-scale demonstrations, and ran primary level trials for the reactors. The data collected allowed us to make proper recommendations on furthering the development of an integrated organic waste system.
Monteverde, Costa Rica is a region known for its biodiversity and environmental prosperity, therefore residents are vigilant about environmental conservation and protection of its limited water supplies. The beauty of Monteverde has caused its tourism industry to flourish, along with the local population, two factors that together have increased the amount of waste generated from local restaurants, businesses, and tourist services such as hotels. Some forms of waste are organics such as food scraps, grease trap materials, animal manure and whey protein. When not disposed of properly, these organic wastes create a myriad of problems in Monteverde including water pollution, solid waste, and greenhouse emissions.

In order to combat the negative impacts of organic waste in Monteverde, we are working alongside Vision to Reality, Ltd, to explore the feasibility of implementing an integrated organic waste system. An integrated organic waste system is a comprehensive waste disposal solution that contains multiple chemical, biological, and mechanical processes that turn organic waste into usable products. Vision to Reality’s proposed system will provide benefits for the Monteverde region by turning their accrued waste into useful commodities that can be utilized in the community.

The integrated organic waste system is composed of 4 technologies: vermicomposting, aerated static composting, bokashi fermentation, and biodigestion. **Vermicomposting** is a process where earthworms are utilized to create compost that has the added benefit of protecting seedlings from pathogens. **Aerated static composting** is...
a method of composting that can treat almost all types of waste feedstocks, which involves putting air through the compost pile, removing any manual labor associate with the process. **Bokashi fermentation** is a process that breaks down more toxic feedstocks through acidification to create a “pickled” byproduct. **Biodigesters** are mechanical stomachs that process organic waste such as grease, food scraps and manures to produce valuable biogas which can be used as fuel. Through utilization of biodigestion, bokashi fermentation, and composting techniques, our team worked with VTR to eliminate organic waste, food scraps, waste vegetable oil, and animal waste from Monteverde’s waste streams and lower greenhouse gas emissions.

**Project Goal & Objectives**

The goal of this project was to improve local waste management techniques in Monteverde by designing an efficient multi-stage waste treatment system that produces usable resources such as enriched soil and biogas through processes including composting and biodigestion. To achieve this goal, we implemented the following objectives:

**Objective 1**

Determine how methods of vermicomposting, aerated static composting, bokashi fermentation and biodigestion can be utilized and integrated to repurpose different forms of organic waste.

**Objective 2**

Determine physical designs for individual reactors within the integrated organic waste system.

**Objective 3**

Design and evaluate the effectiveness of proposed trials through the improvement of waste management strategies.

**Methods**

The first objective was completed through literature review and speaking with experts and local residents on vermicomposting, aerated static composting, bokashi fermentation and biodigestion. This objective provided us with substantial knowledge on how each system operates and provided us with input on how we could experiment with them.

The second objective was completed through building reactors for each of the experimental trials we performed. We built our reactors based on available materials as well as the observations made on existing systems we visited in Monteverde.

The third objective was completed by performing experimental trials in each of the reactors that we built. The trials were observed and monitored to identify any errors which
may have occurred. The results of these observations identified places for improvement within our design, so it can be revised moving forward to secondary trials and the final design.

**Results & Findings**

Although we were not able to fully complete all of our small scale trials, the data collections and observations we made allowed us to draw conclusions for each system.

**Vermicomposting:** We learned that worms’ diets and environmental conditions are not nearly as particular as we believed them to be based on our initial research. We additionally found that the vermicomposting system has an unavoidably slow rate of decomposition. The process was much slower than anticipated and even with variable adjustments we could not increase the rate.

**Aerated static composting:** Through our various trials, Monteverde’s environment calls for precautions when designing reactors. Also, local animals are attracted to food scraps, therefore it is very important that compost piles and vermicomposting bins are properly protected so it is not possible for animals to interfere with the processes.

**Bokashi fermentation:** The trials taught us a lot about how important the design of the bokashi fermentor is, particularly the inclusion of a spigot to allow the system to produce a more consistent and desirable byproduct.

**Biodigestion:** The trials showed us that the amount of processable waste at any one time was much less than expected. Also, we learned from experts that pretreating the organic waste with Mountain Microorganisms (MM) can actually increase the rate at which methane is produced in anaerobic digestion.

Overall, we also learned in our collection of waste from restaurants that it is impossible to attain consistently similar food scraps. This made for more difficult composting because many times the food scraps would have to be sorted through to remove unwanted materials or at least chopped up into smaller sizes. Based on the types of food scraps, it became apparent to us that the collection of organic waste in Monteverde is not yet ready for a large scale operation.

We have developed recommendations that we believe should be applied to each reactor to improve their overall efficiency based on the analysis of our experimental trials.

1. **Send finished samples of aerated static composting and vermicomposting to professional lab for tests.**
   
   VTR should send their samples of the finished soil products to a lab to test the moisture, pH, and nutrients professionally. There is a lab in Turrialba, Costa Rica, Catie Soil Labs, that runs all the need tests at a low price.
2. **Purchase a compost chipper to grind food scraps.**

   There are irregularities in the size and type of food scraps obtained from restaurants, making it difficult to have similar trials and for the food to break down in the time allotted. A compost chipper would ensure equal sized pieces, similar composition within each pile and eliminate the need for the food scraps to go through human preparation.

3. **Build a protective barrier in front of the aerated static compost bins.**

   Animals have managed to get into the bins disrupting the final volume of compost, breakdown of organic material and any measurements or readings. By creating a door with a solid latch, animals will be unable to enter the bin or push down the barrier.

4. **Provide feedstock suppliers with information on categories of waste VTR is utilizing.**

   When the feedstocks were delivered to the farm, we observed that wastes are not properly separated by the categories specified by VTR. We recommend distributing an information sheet on what the different types of food wastes are. In addition to this, we believe that clearly labeling the bins VTR distributes with the categories of food is a critical step in ensuring the proper wastes are entering the proper systems.

5. **Determine the amount of organic waste being produced in Monteverde, Costa Rica.**

   There is currently no accurate number as to the amount of organic waste being created, how much is being put into landfills, or how much is available for VTR’s use in Monteverde. By conducting a survey with restaurants, businesses, and hotels in the area about their organic waste, the actual amount of organic waste not being utilized will be determined. This information can be used by VTR to communicate with the municipality about the cost of contributing to landfills. Creating this relationship with the municipality could potentially encourage them to enforce waste separation techniques on these businesses to avoid excess waste entering landfills. If organics are separated, it will establish a permanent way for VTR to get feedstocks for its reactors. In addition, this will provide VTR with a number of inputs, allowing a better projection for upscaling the facility.

6. **Perform secondary level trials on all of the systems.**

   **Vermicomposting:**
   - Build a new reactor in 5 gallon buckets with sealed lids. This system does not use a lot of space, would keep out wildlife and maintain worm population.
   - Perform secondary trials with direct integration of Bokashi and aerated static composting. This will provide additional data on how feasible this will be in mixing when performing on a large scale.
   - Perform trials with direct food scraps and analyzing how long it will take for the worms to decompose the material. This will determine if the pre composting steps are truly necessary.
Aerated Static Composting:
- Test the proposed recipes that the team created with an organic farmer. These trials are based on a volumetric ratio of 2:1 Carbon to Nitrogen.
- If VTR decides to repeat a recipe based on the results we have, we suggest utilizing the recipe used in Trial 2, based on the data collected this trial was the most successful.
- Suggest using coffee chaff instead of wood shavings because it will break down better and will not diminish moisture.

Bokashi Fermentation:
- Recommend running more trials to further test the bokashi bran to food scraps ratio. Finding this ratio is very important to ensure bokashi bran is utilized in a cost effective manner to maximize the bokashi byproduct’s profit. Using too much bran per batch can equate to a lost profit when using bokashi fermentation in a large scale system.

Biodigestion:
- Test the generation of methane from pig manure without the addition of other feedstocks. Since no methane was produced, this would focus on trying to generate methane from just the manure.
- Continue the pretreatment of the manure with the MM solution with an increased ratio between pig manure to water.
- Utilize the effluent from the biodigester as a fertilizer for plants. By simply drilling another hole and adding another pipe to the IBC tanks, the fertilizer can be extracted from the biodigester.

Conclusion

The goal of our project was to improve local waste management techniques in Monteverde by designing a multi-stage waste treatment system that produces usable resources such as enriched soil through processes including composting and biodigestion. The reactors we built were able to process organic waste and produce some results, however it is difficult to make solid conclusions about each process with the short time span of the project.

Feedstock suppliers in Monteverde are not ready for large scale organic waste collection. Our original thought was that by simply offering to take their waste, local restaurants and food vendors would be more than happy to give us their waste due to our assumption that waste management was a prominent issue affecting the area. It turns out that this is not the case; pig farmers and small scale composters are local competitors for using food scraps, making them difficult to collect. Since these competitors get first claim at food scraps, it makes it difficult for VTR to obtain the quantity of foods scraps necessary for the business.

Our team believes at this point in time additional trials on each system must be performed for longer periods of time. Conducting more small scale trials will provide a better understanding on how to optimize each of the systems. It is also unknown at this time the capacity of waste which can be processed by each reactor, except bokashi, and seeing a trial run start to finish will provide this amount.

This is critical information to understanding the quantity of upscale that needs to occur. In addition, it is important to calculate the actual amount of organics that are available for use in Monteverde. Gathering information on the amount of organic waste thrown away by businesses that is available for use by VTR will provide insight on the size to scale up to. Additionally, it is still unknown whether or not the quality of the products produced by each trial is desired. The byproducts of each trial, once completed, start to finish, must be sent to a lab to have the product evaluated to prove there is value in a finished product.

In conclusion, an integrated organic waste treatment facility in Monteverde has the potential to provide the community with an effective solution to manage the three current issues regarding waste: greenhouse emissions, solid waste and waste water. However, our team believes that in general, more investment into running additional trials, communication with businesses and the municipality is required before implementing the integrated organic waste system on a large scale. We hope that the recommendations we provided can assist with further perfecting of the individual processes and assists in opening up more communication between the feedstock providers to aid further success in the long term project.
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1.0 Introduction and Background

Each year alone, more people die from polluted and unsafe water than from all forms of violence combined, including wars (United Nations, 2014). In the last half century, there has been a dramatic increase in demand for water and food resources due to the exponential growth of the human population. Increased consumption of food and water has led to a radical increase in the amount of organic waste produced worldwide. When not disposed of properly, organic waste creates a myriad of environmental problems, most notably, water pollution.

Monteverde, Costa Rica is a region known for its biodiversity and environmental prosperity, therefore residents are vigilant about environmental conservation and protection of its limited water supplies. The beauty of Monteverde has caused its tourism industry to flourish, along with the local population (Welch, 2016). These two factors together have increased the amount of waste generated from local restaurants and tourist services such as hotels. Some forms of waste including animal manure, food scraps, grease trap materials, and whey protein are causing negative impacts on the environment of Monteverde. According to Justin Welch, a local environmental activist, animal manure slurry is applied to a catchment area putting an important drinking water source at risk of becoming non potable. Additionally, when organic waste decomposes, it creates carbon, nitrogen oxide and sulfur oxide emissions, direct factors in climate change.

Vision to Reality (VTR) is a private enterprise in Monteverde that is currently working to find a sustainable solution for the community’s pollution and waste management problem. The objective of VTR is to address issues of carbon emissions, solid and liquid organic waste, and soil depletion using a collective solution. Vision to Reality has enlisted our team to assist the company in designing a zero emission, sustainable integrated organic waste treatment system. This system will harness sustainable waste management techniques that convert different waste streams into usable resources such as soil amendments. In this chapter, we begin by discussing organic waste and what repercussions arise when waste is left unaddressed. We proceed to explore Costa Rica’s current environmentally sustainable methods of managing its waste. We then explain in more detail Monteverde’s challenges with waste disposal, and the concept of an integrated organic waste system (the proposed solution). We discuss what types of technologies may fit into this facility, and how these technologies have proven to be beneficial in various scenarios.

1.1 Waste Management

1.1.1 Organic Waste and its Repercussions

Discarded organic waste can cause countless problems for communities who do not have a proper waste disposal system in place. The main components of organic waste that are of concern include animal manure, food scraps, and waste contributed to landfills. Animal manure has the potential risk of contaminating water. Food scraps and other organic waste compounds contribute to greenhouse gas emissions when in landfills; improperly designed landfills factor into soil depletion and contamination (US EPA, 2015). Typically, untreated waste in any form when dumped in a localized area, creates a breeding ground for infectious insects and rodents, which often lead to a decrease in local biodiversity (Hoornweg & Bhada-Tata, 2012).

In Costa Rica, fresh municipal water is becoming a scarcity, making it extremely important to put a stop to water pollution (Kinyua et al., 2016). Water is vital to the sustainability of all
human, animal and plant life, making polluted water a detrimental and immediate issue. Animal manure is one of the main contributors to water pollution in Costa Rica (Bower, K. M., 2013). When carelessly dumped in or around water sources, animal manure makes water unusable and unsafe. Burying manure—another common method of disposal—may pollute soil, and through runoff may eventually reach water sources causing additional water pollution (Ladan, 2016). Not only does manure introduce organic matter at potentially high levels, it also introduces pathogens and odorous, volatile compounds (Copeland, 2010). Improper disposal of animal manure creates mass amounts of pollution which decrease freshwater availability and is detrimental for communities.

Costa Rica in particular is struggling with the additional complexity of improper organic waste management and the coinciding problems that occur when waste is improperly placed in a landfill rather than receiving proper treatment. In addition to destroying soil, other repercussions of landfills include the release of methane, creation of water pollution, fire and explosions, vegetation damage, and unpleasant odors (El-Fadel et al., 1997). Due to the infectious materials and their repercussions, landfills produce toxins, called leachates, which lead to unsafe conditions for crop growth or feeding livestock. Leachate is a liquid “formed when rainwater filters through wastes placed in a landfill. When this liquid comes in contact with buried wastes it leaches, or draws out, chemicals or constituents from those wastes” (US EPA, 2016). “The major issue caused with landfill leachates is the leakage of a large number of toxins into freshwater waterways, which ultimately end up in our homes as drinking water or water for everyday use” (WeGreen, 2017).

Solid organic waste is also a significant contributor to the production of greenhouse gases, which cause adverse effects to the environment. Currently in the United States, agriculture contributes up to seven percent of all total greenhouse gas emissions; a portion of these emissions result from the lack of animal manure treatment (Virginia Ishler, 2017). Typically composting of organic wastes, including animal manure but also food scraps and cardboard, also contributes to greenhouse gas emissions (Sánchez et al., 2015). Proper treatment of organic wastes consist of removing any materials, such as carbohydrates, which produce toxic materials within the manure. When manure is left untreated, microorganisms begin breaking down the carbohydrates present in waste, which releases methane and nitrous oxide (Amon et al., 2001). These two compounds, which are prominent greenhouse gases, absorb and trap heat within the atmosphere, steadily destroy the ozone layer, and contribute to global warming and climate change (Amon et al., 2001).

A good portion of the waste streams entering landfills are composed of organic matter, meaning they can be disposed of in alternative ways. Organic materials can be processed through methods of biodigestion or various composting techniques in order to create resources rather than landfills. (Potdar et al., 2016).

1.1.2 Current Initiatives

Costa Ricans are continuously advancing the way they keep their country clean and healthy. There are a few current initiatives that are in place in Costa Rica. Anaerobic Digestion and the Clean Development Mechanism are examples that are being utilized now. Anaerobic digestion has been a very successful treatment method in Costa Rica for processing livestock waste that would ordinarily produce harmful gases. It has been said that:

During anaerobic digestion, both particulate and dissolved organic matter in the waste is degraded to produce biogas, which is mainly used for cooking. Digester effluent is rich in nutrients (nitrogen and phosphorus) and can be used as a soil amendment. These systems
also assist in providing an alternative fuel source, reducing water pollution due to runoff of untreated livestock waste, and decreasing air pollution from biomass combustion (Kinyua et al., 2016, p. 896-910).

“Researchers have observed biochemical oxygen demand and total suspended solids removals of 79 and 86%, respectively, during treatment of swine waste in Costa Rica” (Kinyua et al., 2016). These results suggest that anaerobic digestion can be beneficial in reducing water pollution in Costa Rica by removing the animal manure from the environment.

Costa Rica is also utilizing a Clean Development Mechanism, a method that allows countries to implement an emission-reduction project which works to clean the air by replacing machines that have a high emission level (Potdar et al., 2016). Both factories and the environment are beneficiaries from these systems because replacing these parts allows “factories or electrical generating plants to operate more efficiently—and hence at lower costs and higher profits” (United Nations, 2014). The systems have proven to work well in many countries including Costa Rica, and are continuously appearing throughout the world. In Costa Rica alone, it is projected that 185,825 metric tons of carbon dioxide emissions have been eliminated through systems like these (Potdar et al., 2016). Through the introduction of greener technologies to current infrastructure in Costa Rica, carbon emissions can be reduced. Current initiatives which utilize technologies in Costa Rica work to provide greener methods of managing waste. Anaerobic digesters and other environmentally friendly technologies such as composting provide the framework to combat different issues which are present in the country of Costa Rica.

1.1.3 Monteverde

The region of Monteverde contains seventy-one thousand acres of forest protected by active interests of scientists and conservationists (Nadkarni, N.,Wheelwright, N., 2000). This protection ironically brought forth human population growth, and economic and urban development, all of which created new and complex challenges in managing natural resources such as water and food (Welch, 2016). Using more of these resources has resulted in an increase of organic waste, which has recently become a challenge. In the Cloud Forest of Monteverde, Costa Rica is active in many environmental protection developments involving proper treatment of waste. According to Justin Welch, a local environmental activist, there are three immediate problems in Monteverde that need to be addressed in order to make a considerable difference in the community’s waste treatment; reducing total greenhouse emissions, transportation of waste, and optimizing septic systems.

Costa Rica strives to maintain a healthy environment. With proper treatment of organic waste, detrimental greenhouse gases could be captured, repurposed, and used to provide some benefit to local markets. Repurposing organic waste is difficult because there is a need to transport the waste to management sites that can handle waste properly. Transporting organic waste to treatment facilities uses fuel, which creates an increase in the carbon footprint created by the country. Mr. Welch has informed us that Monteverde is currently in need of alternative methods to treat waste locally and decrease transportation for disposal. Septic systems are used throughout the majority of the Monteverde population, and is the main treatment system for wastewater. Monteverde has one main water shed location, Río Guacimal Watershed; and with increasing population it is important to ensure proper quality and quantity of this water (Welch, 2016). There is currently a pressing need for a collective method which addresses the environmental and social concerns surrounding waste conditions in the community of Monteverde.
1.2 Integrated Organic Waste Systems

In order to combat the negative impacts of waste in Monteverde, Vision to Reality, a private business, is exploring the feasibility of implementing an integrated organic waste system. An integrated organic waste system is a comprehensive waste disposal solution that contains multiple chemical, biological and mechanical processes that turn organic waste into desired products. Everyday in Monteverde many forms of problematic waste including whey, grease, oil, livestock manure, and municipal food waste are created contributing to greenhouse gas emissions, adding to landfills and landfill runoff, and creating water pollution. The purpose of this system is to repurpose the problematic organic waste into usable resources including fertilizer and biogas, that can be sold for a profit or locally used in the Monteverde community. There are various technologies that might compose the integrated organic waste management system including biodigestion, and a variety of composting techniques.

These waste management alternatives produce byproducts that can provide a great benefit to the community. Through waste-to-energy methods, biogases and biofuels are generated and can provide power and heat (Kumar et al., 2017). These gases and fuels serve as local energy sources which administer environmental benefits and reduce funds spent on fuel. Composting within the integrated system transforms the waste into usable fertilizer, which can be sold and used by local farmers and for general gardening. In addition, these systems provide a more economically conservative option because waste will be transported locally to reach the facility that can treat it properly (Sharholy et al., 2008). While there is an initial cost that goes into building an integrated organic waste system, intended to be located in Monteverde, it improves the efficiency and overall response time for waste to be removed from local sources. Also, with fewer vehicles needed for waste transportation out of Monteverde, travel expenses as well as greenhouse gas (GHG) emissions would be reduced (Kumar et al., 2017). Discerning how these individual systems work and learning their associated byproducts will permit a further understanding of the most efficient way of synergizing their processes.

1.2.1 Biodigesters

Biodigesters are essentially mechanical stomachs that process organic materials and turn them into usable resources such as biogas and digestate (Nyirfa, 2014). Digestate is the remaining material after biodigestion. The system starts off by placing organic waste, primarily livestock manure, into an enclosed aerobic and thermophilic tank. The increased heat and oxygen create a setting that allows bacteria to flourish, thus promoting the buildup of beneficial microorganisms in the waste. An example of a small scale biodigestion system is shown in Figure 1.
The organic material within the biodigester undergoes an anaerobic process where the microorganisms break down the organic waste (Caruana & Olsen, 2012). Through anaerobic digestion, usable biogas resources such as methane and carbon dioxide are released from the waste and congregate to the top of the tank, which can easily be extracted through a series of tubing. Eventually, the biogas production will stop, leaving the digestate at the bottom of the tank which can be used as fertilizer (Nyirfa, 2014).

The biogas that is captured from the digester can be utilized as a form of energy. This was attempted on a larger scale in Mexicali, Mexico. The city wanted to increase energy efficiency while decreasing the negative environmental impacts associated with waste disposal (Chavarin, Ojeda-Benitez, Velázquez, & Guadarrama Ramírez, 2006). In a pilot plant, they used anaerobic digestion through a series of biodigesters where tests were conducted to capture and measure the biogas produced. The data concluded that the food waste produced from a family of five could actually satisfy their cooking and heating needs continually throughout the year if converted to biogas (Chavarin et al., 2006). Biodigestion creates a large amount of energy, while providing substantial amount of reusable resources.

1.2.2 Composting

Composting is a naturally occurring biological process that involves the decomposition of organic material by microbial organisms under controlled and aerobic conditions (Vergara, 2012). The microorganisms, including bacteria and fungi, break down the organic material, which can also be found in municipal solid wastes. Once the organic material is broken down by the microorganisms, the end product (compost) can be sold or used as a mineral rich and organic fertilizer (Hopper & Sherman, n.d.). Composting is a unique way to treat organic waste because it can be carried out on multiple scales. From a domestic-scale to an industrial-scale system, the biodegradable waste can be used in production to create compost material for both agriculture and horticulture purposes (Matthews, 2014).

The most important aspect in all types of composting, to ensure a suitable compost at the end of the cycle, is to maintain a proper balance between both moisture and oxygen levels throughout the process (Trautmann, N. M., & Krasny, M. E., 1998). The oxygen and moisture levels of the compost pile determine which form of bacteria, aerobic (aerobes) or anaerobic (anaerobes), will be the primary decomposers in the system. Anaerobes tend to thrive when oxygen
levels drop below the 5% mark and when a moisture level of 50-60% by weight (Smith A., M., & Friend, D. 2015). Anaerobes produce putrid smelling organic acids, hydrogen sulfide, and amines (ammonia-like substances) that have also been shown to be toxic to plant growth (Trautman, N. M., & Krasny, M. E., 1998). The optimal conditions for aerobes to thrive in a compost pile is 5% oxygen and a 50-60% moisture level by weight that must be maintained throughout the process (Trautman, N. M., & Krasny, M. E., 1998). While composting, aerobes provide beneficial nutrients for plant growth including phosphorus, magnesium, and most importantly nitrogen; they also have a more rapid and effective composting rate compared to anaerobes making them most desirable in any composting technique (Smith A., M., & Friend, D., 1998).

Studies in Cuba have shown that 60-70% of Cuba’s municipal solid waste largely consists of organic material that is primarily produced by households (Körner et al., 2008). Landfills are not a common practice, conventional incineration is too resource intensive for the area and the transportation of waste to large waste treatment plants prove to be limited and too costly. By integrating composting at home, results have shown that food scraps and other domestic organic wastes can be turned into fertilizers directly at the source. Decentralized composting plants have not been implemented in Cuba, but the proposed solution would be located on urban agricultural farms where local organic wastes would be brought to produce compost material (Körner et al., 2008). This shows that composting can be utilized on a small scale level with the large scale potential to produce soil amenities from organic waste.

**Aerated static pile composting** is a more time efficient and less time consuming method of composting. It is a suitable method for treating food scraps and paper products, but does not work well for composting animal byproducts or grease from food processing industries (US EPA, 2016). This system works by mixing organic waste with ‘aerating material’ such as loosely piled bulking agents like wood chips or shredded newspaper. An example what an aerated static composting system looks like can be found in Figure 2.

These materials are added so that air can pass through the pile. In many case studies, “changes in the compost chemical characteristics and its stability, as assessed by respiration, indicated that the aeration period did not need to extend over two weeks” (Sesay et al., 1997). This is a more condensed time period than most composting methods, which has proven beneficial for a limited time frame. Aerated static composting is a great way to compost large amounts of waste.
at one time in an effective manner. An advantage of this method is that it can maintain proper moisture/oxygen levels and reduce pathogens because it is ideal for the microbial populations. In terms of soil treatment, aerated static pile composting creates quality byproducts that can be used as mulch, soil conditioner, or a soil amendment. Mulch, soil conditioners, or soil amendments can be mixed into soil to improve its chemical composition. These soil amendments add carbon and nitrogen, as well as beneficial bacteria to soil which is good for crop production (USA Military, 2003).

**Vermicomposting** is a specialized process of composting where earthworms are introduced to a composting pile to assist in the creation of compost (Duong, 2013). This method is commonly used to prevent soil, water, and air pollution while recycling organic waste material and keeping it out of landfills (DeLucia, 2013). An example of a Vermicomposting bin on a small scale is shown in Figure 3.

![Figure 3: Vermicomposting in a Small Scale Bin (Trautmann, N. M., & Krasny, M. E., 1998)](image)

An important specification to keep in mind when vermicomposting is to avoid any kind of meat or cheese byproduct in the compost pile. Some argue that when composted, meat and cheese emit harmful and acidic chemical components that might be harmful to a worm’s diet and could eventually kill them, thus ruining the vermicomposting process (Hacheney & Brown, 2017). One major benefit of Vermicomposting is that it can produce various products from the same kinds of waste depending on what you choose to feed the worms in addition to your waste (Hamilton, 2017). This process is very versatile and allows for different types of amendments to be created based on what is desired. It can also be performed on any scale from a small bin to large bed. In India, discharge of untreated sewage water mixed with agricultural runoff resulted in an increase in water pollution. Through utilizing vermicomposting in India, it was found that the sewage slurry and animal manure could be transformed into fertilizer quality material (Gupta & Garg, 2008). Vermicomposting adds important nutrients to soil, the most important being nitrogen, phosphorus, and potassium (Schuette, E., & Zanin, D., n.D.). Many areas are deficient in at least one of these nutrients, and by adding vermicompost to a crop area, money can be saved on fertilizer. Vermicomposting is a rewarding and unique way to create high quality soil amendments on various scales.

**Bokashi fermentation** is a composting technique that breaks down harmful organic waste into byproducts that can be used as fertilizer or in compost. Bokashi fermentation differs from composting because it is an anaerobic fermentation technique assisted by placing a mix of ‘effective microorganisms’ in a sealed container to break down the constituents (fats, proteins,
carbohydrates) of food scraps until they are pickled (Merfield, 2012). An image of a Bokashi fermentation unit on a small scale is shown in Figure 4.

Unlike traditional composting the Bokashi fermentation process only takes about two weeks to complete. Bokashi has a lack of the putrid smell that composting produces throughout the process because the containers are sealed airtight during the stages where the smell would be most rancid. Even end products do not have a very strong smell because the lack of oxygen prevents odorous chemicals such as hydrogen sulfide and ammonia from being produced (Green, 2017).

One major benefit of using Bokashi fermentation is the variety of waste products that the process can accommodate. In nearly all composting techniques, it is highly discouraged to add any kind of meat, fish or dairy products because they can add toxic materials to the compost, they emit terrible odors, and attract vermin (Merfield, 2012). With Bokashi fermentation the only specification in material input is to ensure there are no oversized chunks of organic wastes in the pile, otherwise any organic material can be added. Also in comparison to composting where a large amount of carbon dioxide (CO$_2$) is released into the atmosphere, bokashi fermentation produces a miniscule amount of CO$_2$ cutting down on greenhouse gases released into the atmosphere. Bokashi fermentation, since it does not utilize aerobic microbes, releases much less nitrogen during the fermentation process than composting, meaning more beneficial nitrogen is leftover in the soil at the end of the process (Hacheney & Brown, 2017).

At the Monroe Correctional Facility in Monroe, Washington, a group of dedicated inmates and advisors created an organic waste management system that processes thousands of pounds of food scraps created monthly by the facility. The system originally was designed as a strictly vermicomposting system and was processing 6,200 pounds of waste per month, but after synergizing the process with Bokashi fermentation techniques to also process the excess dairy, fish, and meat scraps, the system was able to process over 10,000 pounds of waste monthly (Hacheney & Brown, 2017). Using these two systems together provides the Correctional Facility with the ability to increase the amount of food waste that can be processed at a time.

1.3 Our Project

The proliferation of waste that continues to accumulate, hinders communities around the world and calls for changes in current waste management practices. Our sponsor, Vision to Reality,
Ltd, is a company primarily focused on tackling the social, environmental and economic challenges that go hand in hand with waste management; specifically in the Monteverde region. The company has already partnered with the Municipal Government of Monteverde and the Monteverde Cheese Factory in order to establish a cost sharing and collaborative initiative to combat organic waste problems within the community. Vision to Reality suggests tackling three prominent issues regarding waste streams in Monteverde including carbon emissions, waste transportation, and optimization of septic systems through the implementation of an integrated organic waste management system. Vision to Reality’s proposed system will provide benefits for the Monteverde region by turning their accrued waste into useful commodities that can be utilized in the community.

The goal of our project is to create a synergetic integrated waste management system using aerated static composting, vermicomposting, bokashi fermentation, and biodigestion. In terms of Aerated Static Composting, this system can except almost all types of feedstocks. The byproduct is great to use as soil for crop/flower gardens, but in addition the byproduct is treated enough to put into Vermicomposting. Vermicomposting is a sensitive system so the pretreated feedstock must be suitable for the worms’ diet. Bokashi Fermentation creates a “pickled” and very broken down compost which can be placed into Aerated Static Composting and Vermicomposting so that those systems can further break down more toxic feedstocks. Lastly, Biodigestion will treat grease, whey protein, and manure independently from the other three processes to create methane gas to use as a commodity in the future. Through biodigestion and composting we will work to eliminate organic waste, food scraps, waste vegetable oil, and animal waste from Monteverde’s waste streams and lower greenhouse gas emissions.

2.0 Methodology
The goal of this project is to improve local waste management techniques in Monteverde by designing an efficient multi-stage waste treatment system that produces usable resources such as enriched soil through processes including composting and biodigestion. To achieve this goal we implemented the following objectives:

1. Determine how methods of vermicomposting, aerated static composting, bokashi fermentation and biodigestion can be utilized and integrated to repurpose different forms of organic waste.
2. Determine physical designs for individual reactors within the integrated organic waste system.
3. Design and evaluate the effectiveness of proposed trials through the improvement of waste management strategies.

In this chapter, we discuss our approach to achieving each objective and ultimately the goal of our project. We provide logical justification as to why we used specific methods, and what we gained from each individual objective.

2.1 Objective 1: Determine how methods of composting, bokashi fermentation, vermicomposting, and biodigestion can be utilized and integrated to repurpose different forms of organic waste.

Vermicomposting, Aerated Static Composting, Bokashi Fermentation, and Biodigestion are all methods that can be used to transform organic waste into usable resources including,
vermicompost, enriched soil, bokashi byproduct, and biogas. Before designing an effective and efficient experimental trial for treating the organic waste, it was important for our team to learn from experts and online sources about waste disposal treatments. Learning about the different waste management techniques was crucial because they are all sustainable ways to remove and utilize organic waste while creating commodities that can be sold or used. By performing document research and consulting these experts, we were able to further understand what specific parameters we should incorporate in our designs.

Our document research was done through journals, websites, blogs, scholarly articles, and books on all of the different methods and processes. We also collected data on general facts, technological considerations, and experimental procedures on all of the listed technologies. This data provided us with insight into what is currently utilized, how we can use it to perform something similar on our own, and viewpoints of anyone using these processes. We created a table highlighting important parameters within the specific systems including byproducts, time limits, and starting products. This provided us with the proper technical background necessary to formulate preliminary designs for these systems from factual information and additional information of the potential ways to integrate our systems.

We collected additional information on these technologies by conducting semi-structured interviews with local and nonlocal organic waste management experts. Semi-structured interviews allow the interviewer to follow a guide while providing the opportunity to ask questions that may stray from the original plan, giving interviewers the flexibility to ask open-ended and follow-up questions (Cohen & Crabtree, 2006). A list of interview questions can be found in Appendix A. Speaking with experts provided us with substantial knowledge to use while creating our designs. In all forms of composting there are variables that play a key role in the quality of the system’s byproduct. By consulting experts we were able to determine key parameters to include in our final designs ranging from specifics on how the system is physically built to the ratios used in our composting recipes.

We interviewed Marlon Martinez at the University of Georgia-Costa Rica Station, as well as Jorge Mora and Bryan Olivares at the Monteverde Institute, and Alexis Chavarría at Hotel Bellbird on Vermicomposting and Aerobic Composting. We also conducted a phone interview with Luis Carazo at EARTH University and an email interview Fabricio Camacho from the University of Georgia on biodigestion. An interview was conducted with a local pig farmer, Henry Castro on the possibility of providing us with input materials for a biodigester. We also consulted an expert in organic farming, Gerardo Calderon, to gain additional input on making the systems successful. We asked questions that provided information on operating composting systems in the Monteverde region, due to Gerardo’s composting experience in the Monteverde climate, he provided better understanding than any online resource. These questions can be found in Appendix B.

2.2 Objective 2: Determine physical designs for individual reactors within the integrated organic waste system.

The end goal of our sponsor, Vision to Reality, is to combine multiple processes to create a new and effective system for treating organic waste. Eventually, these processes will be combined and scaled up to create a large scale facility with these technologies. However, we are still in the early stages of development and need to experiment on a small scale first. Through this objective, we created drawings for physical designs of small scale reactors that acted as blueprints
when building the reactors. Some of the materials we used were already available for use on the work site. We collected as many materials as we could reuse from the property of our sponsor. Then, we went to a local hardware store and determined what materials were feasible for use within our budget and that would work in our designs. We then constructed the reactors.

### 2.2.1 Vermicomposting

![Vermicomposting Bins Constructed by WPI Team](image)

An image of the vermicomposting bin is shown in Figure 5 above. For the vermicomposting reactors, we zip-tied together 3 avocado crates and used packing tape to close any open edges. Avocado crates were used because they are repurposed and created no cost for our sponsor. We cut holes in-between the bins to allow movement of the worms from one bin to the next allowing us to process a larger volume of waste. The original mesh of the bins was too large to contain the worms, so a thin permeable layer of green landscaping cloth was cut and placed on the bottom of the worm bins to keep the worms in the bins and allow worm tea to flow out. The bins were placed on 3 pallets that we covered in plastic and placed on a slight incline to allow the flow of the tea downwards to collect in a bin at the bottom of the incline. All of the bins were placed in a small amount of sunlight to prevent the worms from escaping the bins without providing too much heat to the bins. A cardboard barrier was placed on top of the bins to protect from animals.
2.2.2 Aerated Static Composting

For the aerated static composting, we constructed the framing of a shed to shield the system from the weather. For the bins, we nailed together pallets to create 5 boxes where we will place the compost piles. First, we leveled the ground so we could measure the height of the piles as they composted. Then we lined the pallets up next to each other to create the five “U” shaped bins with a volume 42.4 cubic feet (1.2 cubic meters). The bins are all 3 ft tall (1 meter) and 3.9 ft wide (1.2 meters). The pallets that are perpendicular to the back wall of the compost bins are all 4.3 ft (1.3 meters) long. The level surface allowed for a barrier of metal to be attached at the end of each bin so the compost was contained and animals were kept out. A metal barrier was chosen because metal will not break down with the compost. We used 2x4’s to support the structure along with 3” and 4” nails to secure it all. The finished product will be covered with plywood or green landscaping cloth on the inside to make sure the compost is contained at all times; this will additionally make mixing/turning the pile easier. An image of the aerated static composting bins we constructed are shown in Figure 6.

After the composting bins were finished, we started designing the aerating pipe system that will add aeration to the piles. We decided to construct two sets of pipes, each with a connection to the blower. One set has three prongs and the other has two. Each prong has a key valve so that we could shut off the air flow to that bin. At the end of each prong there is a three foot vertical pipe with holes drilled into it. In the middle in the bin there is another vertical pipe that is two and a half feet tall also with holes drilled into it. The pipe that sits on the ground between the two vertical pipes also has holes to supply air to the bottom of the pile. Vision to Reality was unable to buy the blower or piping needed to complete the reactor until weeks five and six, so the construction of this pipe system was delayed until then. The layout/shape of pipe system can be seen in Figure 7 below.
2.2.3 Bokashi Fermentation

The “Bokashi Fermentation” system is an airtight container with a spigot on the bottom and a ‘burper’ on the top (Figure 8). The container we used to create the system was a 100 liter barrel with a removable, airtight lid. We drilled a hole in the bottom of the barrel for the spigot...
and drilled another in the lid for the burper; both were made with PVC piping, PVC key valves, and PVC couplings. In order to keep the system airtight, silicone was applied where the PVC entered the barrel. We choose to include a spigot on the bottom of the reactor to drain the liquid or ‘bokashi tea’ daily. The coupling on the internal part of the spigot was fitted with a mesh material that would filter liquid through but keep solid materials from clogging the piping. We decided to include the burper, because our sponsor informed us we needed a way to allow excess gases to escape and deny any unwanted oxygen into the system in order to keep the system’s internal pressure in equilibrium with the external atmospheric pressure. We also needed the burper because the chemical fermentation of organic materials yields carbon dioxide and other gases and it is because of this reaction that he included the burper on his original trial. We were afraid the excess carbon dioxide might build up enough pressure to break the airtight seals or even crack open the barrel over the two week period had we not included a burper.

### 2.2.4 Biodigestion

For the biodigester, we had two 1000 L IBC tanks available on the work site. A 2” hole was drilled on the top of the tank to provide for an outlet for the biogas. The gas outlet was made out of 2” PVC pipe which was reduced to a ½” outlet and fitted with a key valve and water pressure valve. The piping was then attached to clear tubing and connected to a burner. The burner was used to perform tests on whether or not methane gas was being produced. The IBC tanks were then painted black for optimal bacteria growth, thoroughly cleaned out and prepared for trials. Both biodigesters were then brought to a local pig farmer, Henry Castro, to conduct the experimental trials. Since the majority of the organic waste was on the pig farm, loading the material into the biodigester directly at Castro’s farm would be easier than transporting it to the VTR work site. These four reactors will be used to perform experimental trials, which are explained in Objective 3.
2.3 Objective 3: Design and evaluate the effectiveness of proposed trials through the improvement of waste management strategies.

Through this objective we designed primary trials and evaluated if the designs will effectively convert waste into a resource with specified properties. We created a flow diagram that depicted the way we proposed to integrate the systems which can be found in Appendix C. The framework of understanding the technologies and the flow diagrams allowed us to manage the input/output flow of the system and visualize how the entire system operates together (Hebb, N.). The different inputs of the individual trials were put into an excel spreadsheet, which included a list of materials needed in order to conduct the experiments. Some of the experimental trials had to be modified due a lack of feedstock, or of time. The following subsections include the original proposed trials, and the modifications that were actually performed for each system in the project.

2.3.1 Vermicomposting

The designs for primary level trials for vermicomposting, were created based on information we found in both primary level research and findings from Monteverde locals. Since our time frame in Monteverde was only seven weeks, we hoped to perform a pre-composting step on all of trials in order to optimize our time efficiency as well as investigate integration possibilities. We decided to have 5 trials as shown in the table below.

<table>
<thead>
<tr>
<th>Waste Feedstock</th>
<th>Vermicompost-T1</th>
<th>Vermicompost-T2</th>
<th>Vermicompost-T3</th>
<th>Vermicompost-T4</th>
<th>Vermicompost-T5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precompost, Coffee Chaff</td>
<td>Precompost, Coffee Chaff, Bokashi Byproducts</td>
<td>Aerated Static Compost Trial 2</td>
<td>Aerated Static Compost Trial 3</td>
<td>Aerated Static Compost Trial 4</td>
<td></td>
</tr>
<tr>
<td>Additional Feedstock/ Additives</td>
<td>Worms</td>
<td>Worms</td>
<td>Worms</td>
<td>Worms</td>
<td>Worms</td>
</tr>
</tbody>
</table>

Trial 1 only contains pre-composted material to explore how fast the worms would be able to process general pre-composted materials. Trial 2 includes Bokashi byproducts to test whether or not bokashi can be used as a direct input for an integrated organic waste system. Trials 3, 4, and 5 contain pre-composted material from aerated static composting trials, to see what types of materials if pretreated could be used as inputs to vermicomposting. Each trial of aerated static composting used as an input for vermicomposting would have an increased amount of materials known to be harmful for worms if untreated. These trials were designed in an attempt to understand the capacity the worms can handle before they would die.

Due to time limitations and lack of materials, trials 3, 4, and 5 were not able to be performed. Additionally, the original plans for trial 2 had changed. Trial 2 was originally supposed to contain a 1:1:1 ratio of bokashi byproducts to pre-composted material to coffee chaff. However, due to a miscommunication all available bokashi was used after the first 1.5 kg addition. The two trials performed for vermicomposting are shown in the table below.
Table 2: Performed Vermicompost Trial Recipes

<table>
<thead>
<tr>
<th>Waste Feedstock</th>
<th>Vermicompost-T1</th>
<th>Vermicompost-T2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14.5 kg of 1:1 of Precompost:Coffee Chaff</td>
<td>13 kg of 1:1 of Precompost:Coffee Chaff 1.5 kg Bokashi Byproducts</td>
</tr>
<tr>
<td>Additional Feedstock/Additives</td>
<td>1.5 kg Worms</td>
<td>1.5 kg Worms</td>
</tr>
</tbody>
</table>

2.3.2 Aerated Static Composting

The proposed trials for the Aerated Static Composting piles had a lot of input from the WPI team as well as our sponsor and an expert organic farmer named Gerardo Calderon. After our initial research on this composting method, it was found that a good volumetric ratio of carbon to nitrogen was 32:1 based on the fact that we would not be turning this form of composting. However, Mr. Calderon explained the need to keep the ratios closer together in numbers to supply a good end product for the worms in the vermicomposting. We decided to do a volumetric ratio of 2:1 Carbon to Nitrogen. Carbon not only helps the nitrogen break down, but it also helps to create good air flow in the aerated system. Therefore, this volumetric ratio allows for the needed increase of Carbon while considering the feedstocks available to the VTR team. The chart below describes the four outlined recipes for the Aerated Static Compost Reactor for a volume of 1000 L. The trial numbers refer to the bin in which they will be placed and not the order in which they were performed.

Table 3: Aerated Static Composting (ASC) Proposed Trials

<table>
<thead>
<tr>
<th>Waste Feedstock</th>
<th>ASC-T1</th>
<th>ASC-T2</th>
<th>ASC-T3</th>
<th>ASC-T4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>450 L CAT 1 Food Scraps</td>
<td>250 L CAT 1 &amp; 150 L CAT 2 Food Scraps (400 L Total)</td>
<td>350 L CAT 1 &amp; 100 L CAT 2 Food Scraps (350 L Total) 150 Bokashi</td>
<td></td>
</tr>
<tr>
<td>Additional Feedstock/Additives</td>
<td>200 L Ox Manure 275 L Leaf Litter 75 L Coffee Chaff</td>
<td>250 L Ox Manure 275 L Leaf Litter 75 L Coffee Chaff</td>
<td>152 L Ox Manure 133 L Coffee Pulp 275 L Leaf Litter 75 L Coffee Chaff</td>
<td>100 L Ox Manure 275 L Leaf Litter 75 L Coffee Chaff 100 L Grease Solids</td>
</tr>
</tbody>
</table>

After the bins for the reactor were built and feedstocks started to be delivered to the farm, the proposed trial, while ideal, did not happen due to a lack of certain feedstock types or amounts. Below is a chart of the four trials that were performed in the Aerated Static Compost Reactor. It is important to note that trials 1, 2, and 5 are considered aerobic composting because we did not have the materials to perform Aerated Static Composting until Trial 3.
Table 4: Aerated Static Composting (ASC) Conduc ted Trials

<table>
<thead>
<tr>
<th>Date Started</th>
<th>ASC-T1</th>
<th>ASC-T2</th>
<th>ASC-T3</th>
<th>ASC-T5</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/12/18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/31/18</td>
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</tr>
<tr>
<td>2/20/18</td>
<td></td>
<td></td>
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<td>2/13/18</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Waste Feedstock</th>
<th>ASC-T1</th>
<th>ASC-T2</th>
<th>ASC-T3</th>
<th>ASC-T5</th>
</tr>
</thead>
<tbody>
<tr>
<td>133 L CAT 1 Food Scraps</td>
<td>90 L CAT 1 Food Scraps</td>
<td>350 L CAT 1 &amp; 100 L CAT 2 Food Scraps (350 L Total)</td>
<td>130 L Food Scraps (w/ Meat)</td>
<td></td>
</tr>
<tr>
<td>126 L Bokashi</td>
<td></td>
<td>150 Bokashi</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Additional Feedstock/Additives</th>
<th>ASC-T1</th>
<th>ASC-T2</th>
<th>ASC-T3</th>
<th>ASC-T5</th>
</tr>
</thead>
<tbody>
<tr>
<td>190 L Ox Manure</td>
<td>90 L Ox Manure</td>
<td>152 L Ox Manure</td>
<td>380 L of Leaf Litter</td>
<td></td>
</tr>
<tr>
<td>133 L Coffee Material</td>
<td>360 L Wood Shavings</td>
<td>133 L Coffee Pulp</td>
<td>76 L wood Shavings</td>
<td></td>
</tr>
<tr>
<td>5.5 kg Dry MM</td>
<td>144 L Coffee Material</td>
<td>275 L Leaf Litter</td>
<td>10 kg Dry MM</td>
<td></td>
</tr>
<tr>
<td>266 L Leaf Litter</td>
<td></td>
<td>75 L Coffee Chaff</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All trials followed a volumetric ratio of 1:1, except Trial 3. The trials were conducted this way because of the different amounts of wastes we had available at the farm. This may not be what was proposed but knowing the outcomes of these trials is beneficial to make future trials.

2.3.3 Bokashi Fermentation

The originally proposed trials for bokashi fermentation are the same as the trials that we were actually able to perform. Both of these bokashi trials were performed with a spigot. Although we wanted to test the difference between bokashi with a spigot and bokashi without a spigot directly, our sponsor already provided us with data from a bokashi system without a spigot. Since we had the data, we decided not to replicate this, as we could utilize the feedstocks for other trials. Below is a chart that elaborates on the input differences of the two individual trials we performed.

Table 5: Bokashi Fermentation Performed Trials

<table>
<thead>
<tr>
<th>Waste Feedstock</th>
<th>Bokashi-T1</th>
<th>Bokashi-T2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAT I &amp; 2 Kitchen Waste</td>
<td>CAT I &amp; 2 Kitchen Waste</td>
<td></td>
</tr>
<tr>
<td>CAT 1 &amp; 2 Kitchen Waste Meat Scraps</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Additional Feedstock/Additives</th>
<th>Bokashi-T1</th>
<th>Bokashi-T2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bokashi Bran</td>
<td>Bokashi Bran</td>
<td></td>
</tr>
</tbody>
</table>

The main differences between the two trials is that Bokashi-T2 included meat, as well as a different ratio of food to bokashi bran. Trial 2 has a food to bokashi bran ratio of 5 gallons of food scraps to two handfuls of bran, while Bokashi-T1 has a ratio of 3 gallons of food scraps to two cups of bran. The reason for this difference was to test cost efficiency with the resources we had and to use the smallest amount of bran as possible for future trials.

Although the trials had different inputs and ratios, both had been prepared with the same process. The process included sprinkling two cups of bran on the bottom of the barrel, adding in
food scraps, then using a flat surface to compress it to the bottom of the barrel before beginning the next layer. This was to remove air bubbles from the pile that would have added unwanted oxygen to the system.

2.3.4 Biodigestion

The proposed trials for biodigestion were created based on the information from experts and further research. For the two trials conducted, the primary feedstocks included were pig manure and grease trap material along with water. Only 18 L of the grease was put into each of the two biodigesters and a ratio of 1 kg of manure to 20 L of water was maintained until a total volume of 700 L was reached.

Table 6: Biodigestion Performed Trials

<table>
<thead>
<tr>
<th>Waste Feedstock</th>
<th>Biodigester-T1</th>
<th>Biodigester-T2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grease trap material (CAT III) Pig manure (CAT IV)</td>
<td>Grease trap material (CAT III) Pig manure (CAT IV)</td>
<td></td>
</tr>
<tr>
<td>Additional Feedstock/Additives</td>
<td>None</td>
<td>Pig manure pretreated w/ MM (24 hours in advance)</td>
</tr>
</tbody>
</table>

The difference between the two trials was that Biodigester 2 had the pig manure pretreated with Mountain Microorganisms (MM), a fermented liquid solution. Tests were done to see how much methane would be produced through the burner. Using a lighter, if a flame was produced, that would be a sign that methane was produced within the biodigester.

We created working experimental procedures for how each primary level trial was operated. This allowed the trial to be performed properly and allowed for replication to be performed in the future if necessary. The experimental procedures can be found in Appendix D. Throughout the trials, we carefully observed and monitored the reactors and identified any errors which may have occurred. The results of these observations identified places for improvement within our design, so it can be revised moving forward to secondary trials and the final design. The results additionally provided us with important data on the effectiveness of each individual process and the quality of the product they produced. By understanding the quality of the product, proper recommendations can be made in order to optimize the proposed design. As our trials begin to come to a close we have more of an understanding of the data that we have gathered.

3.0 Results and Analysis

In this chapter, we present our findings based on four themes for each different reactor: vermicomposting, aerated static composting, bokashi fermentation and biodigestion. In the beginning of each section, we provided the results from the meetings and interviews we have conducted with waste management experts that have influenced our experimental trials and results from the data we have collected from each reactor. We concluded each section with relevant findings from each reactor.
3.1 Vermicomposting

Initial research showed us that Vermicomposting is an extremely sensitive system that required a lot of monitoring. Red Wiggler worms, also known as composting worms, are hypersensitive to the food included in their diet and the environment they are kept in. Certain types of organic wastes including acidic foods should not be given to the worms, because they cannot survive in acidic conditions (Grant, A., N.D). Various online blogs additionally indicated that the worms should be able to process anywhere from half of their own weight to three times their weight in waste per day (How much waste can worms eat?). If the worms are processing all the inputs, there should be no odor associated with the worms, an indicator that this is the correct amount to feed them (How much waste can worms eat?). Due to the fragility of the worms it seemed we were going to need to proceed with extreme caution on the quantities and quality of food we fed them. In terms of environment, monitoring humidity is important, because worms need a moist environment to survive. Initial research also indicated worms should be kept in complete darkness (Grant, A., N.D).

After speaking with local individuals on three different vermicomposting systems, we discovered all of them were set up to deal with excess of food scraps, leaves, and kitchen scraps that the locals did not want to throw into a landfill. The byproducts of all these waste materials created valuable and useful gardening products such as soil and fertilizer.

Marlon Martinez at University of Georgia told us about the Vermicomposting system he had set up there, which was a large trough system that processed 500 kg of material per month. The material entering the system was pre composted organic material (two months of composting) before being put into Vermicomposting. The system had no odor because they used mountain microorganisms (MM), which are microorganisms that reduce odors and accelerate decomposition rates in the compost. One issue with this system occurred when the worms had a plastic cover as a barrier, they tried to escape the bins. They decided to use sunlight as a natural barrier instead; this worked because worms’ natural instinct is to avoid sunlight. In addition, when they used total darkness the worms were thinner compared to when the top of the bins were exposed to sunlight. This information is important to know, because thinner worms correlate with less processing of material. The system involves removing worms by hand with a wire sifter, which is difficult and time consuming.

Jorge Mora and Bryan Olivares at the Monteverde Institute had a smaller Vermicomposting system compared to the one observed at the University of Georgia. Their system is enclosed in a shed with very little lighting that operates by adding thin layers of direct waste into a large bin at a continuous rate. The process start-to-finish takes approximately six weeks. The system attracted a lot of fruit flies, because the food they are giving the worms are direct food scraps that have not been previously composted. These flies can be a problem because they lay eggs for maggots in the compost, a complication important to avoid. The system also has a bad odor associated with it, an indication that food may be spoiling rather than being broken down by the worms. To remove the worms from their final product, they place horse manure in the center of the pile and the worms migrate to it because they like to eat it and while the worms are consuming the manure they collect the product.

Alexis Chavarria a local hotel owner, utilizes a vermicomposting system in his yard that consists of a pile of organic waste in his backyard. The system has no barriers or covers to prevent the worms from escaping and to keep them out of the sunlight. He puts direct, whole food scraps into the bin, a very different approach than the other two systems we visited. These foods include acidic fruits which his worms have never had a problem handling. His vermicompost pile also
always smells, an indicator that he might be feeding his worms too much material. He does not usually monitor how long it takes to process material start to finish, but he noted it takes a very long time for them to completely digest material.

After visiting systems and reviewing literature, the trials described in Objective 3 were performed. An image of the vermicomposting system can be found in Figure 10 below.

![Figure 10: WPI's Vermicomposting Bins Trials 1 and 2](image)

Trial 1 was a test run for us to explore exactly how fast the worms would be able to process general pre-composted materials. Pre-composted material is already partially broken down, so it was hypothesized that this was an optimal system that would be processed by the worms faster than direct food scraps. After a week, Gerardo Calderon, an expert organic farmer, informed us that the worms were still very slow in the decomposition process and it would in fact require a minimum of two months processing time before adequate benefits were added to the soil.

In trial 2, it was hypothesized by the team based on research findings that putting bokashi byproducts into vermicompost without being pretreated would kill the worms, due to extreme acidity of that feedstock. Trial 2 of Vermicomposting was a mixture 1:1:1 ratio of bokashi, coffee chaff, and pre composted material. It was predicted that after 24 hours the worms would no longer be alive due to their inability to survive in an acidic environment. It was found that the worms did not die, and were able to survive the acidity of the mixture provided to them. The worms would have been provided with more bokashi after initial feeding, however due to a miscommunication all the bokashi byproducts were used in trial of aerobic composting. Because of this, trial 2 additionally became a second experimentation on determining the rate at which the worms could process material. After three weeks, in both trials there were some parts where a noticeable difference in the fibrous amount of material was present in the inputs, however this was a very small amount of material. Through the information collected and observations made, the following findings about vermicomposting are concluded.

**Finding #1: Vermicomposting systems are extremely versatile and are not greatly affected by the conditions of their surroundings.**

Our team was extremely concerned about the ability to keep the worms alive based on our initial research. This research indicated that pathogens in manures would be harmful to worms and could potentially kill them. At the Monteverde Institute, horse manure is directly placed into their worms, and rather than killing them, it actually attracts them. In the trials with Bokashi, we thought the worms would die after 24 hours due to the acidity, however it does not kill worms when mixed with a ratio of other materials. Additionally, research indicated that worms need to be kept in complete darkness, however in Monteverde many of the systems we observed used sunlight either directly or indirectly. In two of the systems we visited, we observed that organic material without
any sorting of food was placed directly into the system and the worms still survived. There are some limitations involved with the systems which was indicated by the odorous smell in the Monteverde Institute and Alex Chavarría’s systems. This limitation occurred when the system is overloaded with more food scraps than the worms can intake. This is an indicator that the food begins rotting rather than being consumed by the worms. Overall, vermicomposting systems can withstand a large range of inputs and environmental conditions, making it an extremely versatile process which can be used for a variety of purposes.

**Finding #2: Vermicomposting systems have a slow rate of decomposition regardless of food inputs and environmental conditions.**

When direct food scraps are given to a vermicompost system, it is expected that it will take a 2 to 6 months for the worms to completely break down the inputs. Online research suggested by using precomposted material it would be possible to optimize the system and allow the worms to completely process pre composted material in 2-3 weeks. Trial 1 was completely optimized to test this theory, to see how long it would take for worms to break down fibrous pre composted materials. Even when the worms were given neutral coffee chaff and pre composted food scrap materials, what can be considered optimal feeding inputs, Gerardo Calderon informed us that they were still very slow in the decomposition process. It was also noted that in every system we visited, the minimum amount of time any of them took was 6 weeks, which suggests a slow rate of decomposition in all three situations. Overall, there is not a known way to accelerate the vermicomposting systems.

### 3.2 Aerated Static Composting

During our initial research on Aerated Static Composting, we found that we could treat the most waste using the pile method, where waste is piled ranging from four to eight feet high and ten feet long (USA Military, 2003). In aerated static compost there in no need to turn the pile so the amount of waste is not a major consideration. In spite of that, the pile method did not seem like a good idea for the farm in particular as it requires a large the amount of space and large amount of feedstock to complete multiple trials. VTR is on a mission to treat waste in the most cost effective and efficient way, and in order to figure out the best way to do this, different trials must be run to find the best mixture of feedstocks and additives. VTR currently lacks the amount of materials needed to use the pile method. Additionally, the bin method gave us a chance to create multiple trials. Finally, the bin method supplies better protection for the compost. Monteverde has a great deal of free roaming wildlife that creates a risk of animals ravaging within the piles, a difficult issue to cope with.

As stated in the methods chapter, trials 1, 2, and 5 were not the proposed mixtures. However, trials 2 and 3 were volumetric ratios of 2:1 Carbon to Nitrogen. Trials 1 and 5 had a volumetric ratio of 1:1 Carbon to Nitrogen. However, during our trip to the University of Georgia Costa Rica, Marlon Martinez, discussed that a typical compost pile has a 1:1 volumetric ratio and the only issues we found with his piles were that they had a slight smell to them. In addition to Martinez’s piles, VTR had started a compost pile before we arrived that also utilized this ratio. Both systems showed the need for a long turnaround time, they smelled putrefied, and the food was still in big chunks months after composting. With the 2:1 volumetric ratio of Carbon to Nitrogen in Trial 2 the smell of the original food was eliminated within 3 days. The food chunks in this trial were breaking down by day 6, and by day 14 the food was unrecognizable.
Additionally, we had to discuss a timeline for the composting piles. Through initial online research it was found that the shortest amount of time that aerated static composting needs is two weeks but due to the delayed construction of the aerating pipes of this reactor, we had to switch for the time being to aerobic composting. After speaking with Marlon Martinez about traditional aerobic composting we decided to take his timeline into consideration and see if it could be shortened. Mr. Martinez has a series of six aerobic compost piles that are turned and composted for five to six weeks at a time. These piles are pretreated to feed his vermicomposting bins, which is a similar end goal to VTR. Gerardo Calderon and the WPI team sat down and discussed a 22 day timeline, which is about the average of the two time ranges. This gives the compost a little extra time to become less acidic and cooler for the worms in the vermicomposting bins.

From Trials 1 and 2, we gathered important information regarding the effectiveness of the proposed recipes. These two trials have different recipes and volumetric ratios. Below are the graphs of the temperature, pH, moisture, odor strength, and odor category for the two trials. It is important to note that Trial 1 started 13 days after Trial 2, and due to the time frame we are in Monteverde, not all of the data could be collected for Trial 1. All of the data charts can be found in Appendix E.

3.2.1 Graphs of Data for Aerobic Composting

![Figure 11: Graph of Temperatures for Aerobic Composting Trials](image)
Figure 12: Graph of pH Levels for Aerobic Composting Trials

Figure 13: Graph of Moisture Levels for Aerobic Composting Trials
The first graph (Figure 14) depicts the temperature of trials 1 and 2. In composting the pile will heat up as the materials start to break down. The piles should exceed 140 °F (60 °C) to indicate decomposition is occurring optimally. As the chart shows both piles reach over 140 °F (60 °C). It
is additionally important to reduce the temperature to below 95 °F (35 °C) in order to deem it safe to use in the vermicomposting. Trial 2 did so within the trial timeline of 22 days, and Trial 1 is predicted to do the same. A graph which describes the pH levels of the two trials is shown in Figure 12. In composting, an additional indicator that the process is completed is achieving a neutral pH of 7. Trial 1 continued to increase in pH as the data was collected while Trial 2 became neutral and remained neutral. A graph for moisture level was also created for the trials (Figure 13). As the composting process proceeds, it is desired that the moisture level will decrease but not become eliminated. It is unclear what the ideal moisture level is at this time. Trial 1 seems to be following a similar trend as Trial 2.

A graph displaying the odor strength of the compost for the two trials is shown in Figure 14. The odor scale is from 1 to 3. One is No Odor, 2 is Mild Odor, and 3 is Strong Odor. One of the team's main concerns with the composting piles is odor. We are looking for recipes that have No Odor as quickly as possible. Trial 2 was odorless very quickly, but Trial 1 still has a Mild Odor. The final graph is of the odor category (Figure 15). This data also has a scale from 1 to 3; 1 is Compost Material, 2 is Original Material, and 3 is Putrefied Material. As a team, we want the piles to reach Compost Material stage because this indicates that we have a sufficient mixture for composting. Both trials reached this stage within days of each other.

As the trials came to an end, it was clear that within each composted pile the material was different in size. Each pile had big chunks, medium pieces, and fine soil. The fine soil is the ideal product and so we needed a way to sort the material. The team designed a compost sifter that was later built by William Arguedas at the Municipal Recycling Center shown in Figure 16.

By rotating the handle the compost sifter spins and the fine material drops through the bottom to be collected. The larger material comes to the end of the sifter to be gathered and placed back into the compost pile to break down further.
Finding #1: Due to Monteverde’s weather and wildlife, precautions must be taken when choosing a composting method.

In composting, a multitude of food wastes are being broken down with the help of different carbon sources to make a nutrient rich soil. The organic material that is broken down by the compost pile has had the tendency to attract local wildlife. On multiple occasions they have eaten and dismantled the composting piles when the front of the bins were left exposed. Along with the wildlife of Monteverde, we had to consider the weather in the area. Monteverde is a windy, rainy, and cold area of Costa Rica. A compost pile can not be overly wet, or be exposed to a lot of wind because the pile would be disrupted. Due to these considerations the pile system we originally planned to use, opposed to the bin system we are utilizing, would be very difficult to use in Monteverde. In the pile system, the best way to protect the freestanding piles would be by placing a layer of landscaping fabric over the pile or by creating fence to completely encompass the area. The landscaping fabric would make it very easy for wildlife to penetrate and destroy the pile, Additionally, landscaping fabric is permeable and the water from the excess rain would make the piles too moist. Also the fencing option would not only be very expensive but would not guarantee the safety of the pile. It is important to take precautions when composting because the rate of success is dependent on temperature and moisture; which can all be compromised by Monteverde’s constantly changing environment. A compost pile must heat up to at least 140 °F (60 °C), and it starts to do this as it sits static. If the piles were to be disrupted it may not heat up to 140 °F (60 °C), therefore extending the length of the trials. Also with extra, unwanted moisture added to the pile, odor could increase and the trials could require more time. For the best timeline and odor level, protection of the compost piles is very important.

Finding #2: The ability to obtain consistent food scraps is a considerable challenge due to the irregularity of the food discarded from each supplier.

While composting, it is important that the food scraps are of a similar size. This is because a compost pile with similarly sized food scrap pieces will uniformly decompose at the same rate. The food scraps we received from local restaurants came in all different sizes. The best method we came up with to get the food into similar sizes is to chop up the food scraps using machetes and shovels. This can be a hard task in itself because it is tedious, time consuming, and is still inconsistent in creating uniform food pieces. The physical content of the food waste is another complexity because we had no way to predict what would be in the bins when they were dropped off. Some of the bins contained high water content and citric foods, which can create complexities with the inputs to our trials. The added water affects the moisture of the piles and the pH can be affected by the amount of citrus introduced to the pile. Further separation or additives was considered for these trials to counteract these types of foods, and this disrupts the original recipes.

Finding #3: The feedstock supply received is not always properly separated by desired categories which hinders the creation of composting piles focusing on certain waste categories.

The feedstocks that VTR has been receiving have not been separated into the categories that we wished to use for the suggested composting trials. This can happen for a multitude of reasons, however the actual reason is unclear. One possibility is that it may not have been conveyed what can and cannot be considered organic, and it is unclear to the supplier what should and should not be collected. Many of bins VTR collected had contained rubber gloves, tin lids, plastic bags, and general garbage, none of which can be composted and have to manually removed. Certain
trials performed on the farm are sensitive to the types of the feedstocks collected by VTR. The recipes that have been created are designed to test the effectiveness of the mixture for certain categories of food. When a bucket of feedstock has multiple categories of food waste, it is hard to say how effective the recipes are. Each trial is set up to contain different categories of food (See Appendix F for the Category chart) and a trial’s timeline, pH, and moisture can change based on which feedstocks entered. If the feedstocks are different from what was originally anticipated, we must change the recipes, and it may be hard to use the byproduct for other systems. This becomes a potential problem in the integration of systems.

**Finding #4: Feedstocks are not readily available for use in the systems.**

VTR spent time prior to our arrival in Monteverde trying to determine different suppliers for organic feedstocks. However, when we decided on which waste products were needed for each trial we found that we did not have the supply of feedstocks ready at the farm. Different suppliers including restaurants and supermarkets were not always willing or able to provide us with their wastes for many reasons. The main supermarket of Monteverde requires a permit from the government saying that we are a waste treatment initiative that will not be reselling the food. Even after obtaining the permit, the supermarket decided not to give us food waste based on a company policy created by their corporate office. Another restaurant wanted bins to put the food scraps in. Until we supplied those, we were unable to get the waste from them. Other possible suppliers in Monteverde were unwilling to give their food waste because they already have a composting/treatment routine in place that works for them, and it would be a large hassle for them to switch what they are doing already to supply for future use at VTR. It is also possible that there are other businesses in Monteverde that have not yet been identified as feedstock providers that we could look into for partnership. Overall, the process for collecting feedstocks is still being developed, and this creates limitations in VTR’s waste treatment goals.

### 3.3 Bokashi Fermentation

Based on our preliminary research and our consultations with our sponsor Justin Welch we created final designs for two bokashi fermentation reactors. One aspect we wanted to test in Bokashi Fermentation was the importance of a spigot in the bokashi fermentation trails. Our sponsor, Justin Welch began a bokashi fermentation trial without the use of a spigot that was completed about a week after we began our project. When we reviewed the results of his trial we found that over half the container of fermented material was sitting in liquid or ‘bokashi tea’. The liquid buildup in Mr. Welch’s trial caused the final product to be saturated in liquid, making the product difficult to handle.

For the additional trials, we included a spigot on the bokashi reactor. We hypothesized that the product of this reactor would create a drier, more desirable bokashi byproduct. During the two week long fermentation process, we used to the spigot to drain bokashi tea daily. When our trial concluded, we found the byproduct was not soaked like it was in Mr. Welch’s trial. The bokashi byproduct was easier to handle because there was no saturated liquid. In terms of acidification, both trials with and without a spigot were equally acidified based on the smell they had.

**Finding #1: The use of a spigot creates a more desirable end product for bokashi fermenters**
The largest difference that could be identified between utilizing a spigot or not can been seen in the product which was produced by each set up. Daily use of the spigot to drain the bokashi tea from the reactor created a drier, more desirable bokashi byproduct which had no saturated liquid. The saturated liquid in Mr. Welch’s trial interfered in our weight measurements when we went to integrate the bokashi byproduct into other composting processes. The dry bokashi byproduct allowed us to weigh it without worrying about the weight of the absorbed liquid interfering with our measurements. Accurate measurements allowed us to stay true to our intended composting ratios when using bokashi byproduct in other forms of composting techniques. Since we planned on integrating bokashi fermentation with the vermicomposting system with worms whose diet is very particular, inaccurate measurements could have potentially killed off the worms. The inaccurate measurements could also disrupt the combination of bokashi fermentation with aerated static composting; a process that utilizes very particular ratios of carbon to nitrogen to produce specific compost products.

3.4 Biodigestion

In the research we conducted for biodigestion, we learned aspects of both the physical construction and the feedstocks going into the biodigester. Anaerobic digestion undergoes a four step process in order to decompose organic material and produce biogas: hydrolysis, acidogenesis, acetogenesis and methanogenesis. When placing organic feedstock such as livestock manure and food scraps into a biodigester, they must first be broken up for bacteria to effectively access and break down the material. Methanogens are microbes that are responsible for producing methane in anaerobic digestion and can directly produce methane from the hydrolysis stage in a small amount (Triantafyllou et al., 2014). Since the organic matter is still not completely broken down after hydrolysis, the waste then moves onto the next steps of the process where different types of bacteria and microorganisms continue to break down the organic waste (Khalid et al., 2011). The optimal pH for the methanogens to effectively operate within the biodigester is relatively neutral between 6.8-7.5 (Ali Shah et al., 2014). The entire anaerobic process is shown below in Figure 17 (Managing digester feedstocks, 2016).

![Figure 17: Biological Process of Anaerobic Digestion](Managing digester feedstocks, 2016)
For the building process of the biodigester, we followed a similar design by Solar C³ities who utilized an IBC tank as a biodigester which is shown in Figure 18 (Chase, 2015). One overlooked aspect of the biodigester in our research involved the physical appearance of the container. On the Solar C³ities website, they suggested that the IBC tank must be painted black so sunlight would not penetrate the tank and effect the trials. If a large amount of sunlight is emitted through, the production of algae would then flourish. Algae requires carbon dioxide to grow and releases oxygen (Wang et al., 2017). In the acetogenesis stage of anaerobic digestion in Figure 17, one of the intermediate products includes carbon dioxide. If the carbon dioxide in acetogenesis is not directly used by methanogens, the production of oxygen from algae would hinder the amount of methane produced during the methanogenesis stage and the biogas collected would then be mostly carbon dioxide. Painting the IBC tank was necessary to provide an opaque surface to prohibit the growth of algae and control the biological processes occurring within the biodigester.

For the organic wastes going into the biodigester, we learned about feedstocks in a phone interview with Luis Carazo, a professor at EARTH University in Guacimo, Costa Rica. EARTH University is an institution that provides an education in agricultural sciences and natural resources management, promoting sustainable development and conservation (EARTH University, n.d.). Also, Mr. Carazo is a professor of agronomy, which is the study of soil management and field-crop production, and is head of Sustainable Agricultural Development. Mr. Carazo gave us information about the materials that could be put into the biodigester and recommended quantities for each feedstock. Based on the talks with experts like Mr. Carazo and additional research, it led to our first finding.

Finding #1: The capacity to process larger amounts of organic waste was less than first anticipated.

During the first week of work, the team discussed potential organic wastes to put into the biodigester along with corresponding ratios. Some of the possible feedstocks included pig manure, grease trap material, whey protein, food scraps and mixtures of the waste. Originally, the team wanted to conduct trials to test at least two different feedstocks with the IBC tanks we had available, to see how much methane could be produced, and compare the processing differences of organic waste. Pig manure would be in both trials but the two other primary feedstocks we wanted to test were grease and whey protein. The grease would be obtained from local restaurants.
and the whey would be from the Monteverde Cheese Factory. We wanted to set up trials that included an equal 1:1 ratio of pig manure to grease trap material to maximize the amount of waste we potentially could process. Since no ratios were found on how much whey could be processed in our research, the ratio for the whey was undetermined. We wanted to contact people, like Mr. Carazo, to gain more information on biodigestion before actually starting our trials.

When speaking to Mr. Carazo, we realized that the amounts of waste we wanted to process would not be feasible. Mr. Carazo had advised that the biodigester should only be filled to a maximum of 90% of the total volume to not overflow the system. However, for the actual feedstock ratios, he stated that the maximum percentage of grease that should be allowed in the biodigester could only be 2%. As far as livestock waste, Mr. Carazo suggested using 1 kg of pig manure for every 20 L of water. Then when we asked how much the whey should be placed in with the manure, he suggested that a maximum of 30% of whey would be sufficient. Ammonia is produced in the acidogenesis stage and could potentially disrupt the pH within the biodigester.

This was a significant difference compared to our original feedstock ratio. The information we got from Mr. Carazo showed us how much biodigestion can process organic wastes such as manure, fats and oils. While it deterred our initial plans for biodigestion, Mr. Carazo gave us information on potentially using Mountain Microorganisms (MM) to pretreat the organic waste. This led us to take a new direction for our experimental trials.

**Finding #2: Organic waste can be pretreated with Mountain Microorganisms in order to accelerate the production of methane.**

Mountain Microorganisms are naturally occurring bacteria in the soil that are typically found on the forest floor. MM is primarily used for soil health and fertility where it is used to help prepare fertilizers. The MM are mixed with rice bran and molasses to make an additive, increasing microbial activity, so that it can be sprayed onto plants and crops (Montgomery, 2017). MM is very commonly made and practiced in Latin American countries because it is a cheap and effective method for plant growth. However, for the pretreatment of organic wastes, applying MM increases the rate at which organic material breaks down (Joseph & Chacon, 2010).

Mr. Carazo claimed that if a mixture of the pig manure had a fermented MM solution applied to it 24 hours in advance to being loaded in the biodigester, that it could accelerate the process of producing methane. This was verified when we contacted Fabricio Camacho, who works at the University of Georgia campus in San Luis. Mr. Camacho has done extensive research and published journal articles in anaerobic digestion and biodigesters. The biodigester at UGA has also been in operation for 5 years, so it provided us with a good reference to work from despite not being able to physically see it during our visit. In the emails with Mr. Camacho, we asked questions regarding the primary feedstocks, ratios, maintenance and any problems their biodigester has experienced. When we asked him about waste pretreatment, he said that they pretreat the livestock manure with the MM solution at the UGA biodigester.

Based on our previous research, we had found no literature that provided information regarding pretreatment of feedstocks with a fermented solution. Journal articles, videos and online sources showed designs, materials and methods where pretreatment of manure was not necessary and the production of methane gas would continue regardless. Methods to accelerate the process largely consisted of heating the biodigester to temperatures above 120 °F, but no catalytic additives
were mentioned. Since the MM solution is commonly used in the region, it appears to be an effective method for both plant growth and biodigestion.

The information we received allowed us to devise new trials to run our experiments. Within the 1000 L IBC tanks, we decided to only fill it up to 700 L rather than the maximum volume Mr. Carazo had previously told us. Since we did not have an additional apparatus to collect the biogas, we decided to compensate for the amount of gas created. Being the first attempt, we left 30% of the total tank volume as a reservoir to leave enough room for the build up of gas. As a safety precaution, we added burpers coming out from the PVC pipe in order to relieve the pressure inside the biodigester.
As previously stated in the methodology, the ratios of feedstock were only 18 L of grease trap material in both biodigesters along with 1 kg of pig manure for every 20 L of water maintained until it was filled to 700 L into Biodigester 1. For Biodigester 2, the same ratios of feedstock were added except the pig manure was pretreated with the MM solution 24 hours in advance. The pretreated mixture would test how much faster methane is being produced, compared to the untreated manure, based on the amount of time the burner would be able to hold a flame.

Based on the seven week time frame, we were unable to see actual results for the experimental trials testing the pretreatment of pig manure with MM. From a two week analysis of periodically testing both biodigesters, we found that no methane was being produced in either trial since no flame appeared in either of the two tanks. Despite this result, the IBC tanks noticeably expanded the day after the feedstocks were loaded. This does suggest that there is gas building up, mostly likely carbon dioxide, within the biodigester opposed to methane. Based on this analysis, we believe that the process takes longer than two weeks to see results. It is also possible, that the added grease feedstock could have been too acidic for the biodigester to effectively operate, leading to an assumption of problems concerning the feedstocks and ratios in the first two trials. While the majority of the systems were not able to be fully analyzed due to time constraints, we provide recommendations and discuss the potential next steps of the project in the following chapter.

4.0 Recommendations and Conclusions

During the trials we completed for each reactor we came to realize that we made many mistakes in both the physical and procedural designs. Each mistake offered us an opportunity to reflect on what changes could be made in order to improve the reactors. This section has a detailed layout of recommended specifications that we believe should be applied to bokashi fermentation, vermicomposting, aerated static composting, and biodigestion to improve their overall efficiency. We also compile the results and recommendations to draw conclusions for the project.

4.1 Recommendations

We recommend running professional lab tests on the aerated static composting and vermicomposting finished product. One very important part of utilizing compost as a commodity is the levels of nutrients, pH levels, and the amount of moisture present in the compost. On the farm there is a meter used to test the pH and moisture, but we have no way of knowing what nutrients are within the compost. As a team we are proposing that VTR sends samples of the finished products to a lab to test the moisture, pH, and nutrients professionally. There is a lab in Turrialba, Costa Rica, Catie Soil Labs, that runs all the need tests at a low price. A price sheet can be found in Appendix G. It is about a six hour drive from Monteverde, but this lab accepts mailed samples and will email a results sheet to the provider upon completion of the tests. With all the tests being relatively easy to request, Catie Soil Labs seems like the best choice for VTR’s needs. (https://www.catie.ac.cr/en/products-and-services/high-level-consulties-and-services/laboratories/soil-laboratory.html)

We recommend purchasing a compost chipper to grind food scraps. Due to the irregularity in size and types of food scraps, it can be difficult to compare trials that have different sizes of food scraps. The current methodology is to chop the food scraps manually with a machete. This process is time consuming, dangerous, and tedious. Due to this, we propose the purchase of
a compost chipper. This would eliminate the need for the food scraps to go through human preparation, a very time consuming and nonuniform process. When the bins of food scraps are obtained from the restaurants, VTR can put them into the chipper and the food scraps will all be broken up within moments. This is the easiest way to ensure equal sized pieces and similar composition within each pile. This model will work on all the types of organic food wastes we are working with. Below is a link to a popular model that should suit VTR’s process. (https://www.amazon.com/WORX-Amp-Electric-Leaf-Mulcher/dp/B002MAPZYC/ref=sr_1_2?ie=UTF8&qid=1518559441&sr=8-2&keywords=compost+shredder)

We recommend building a protective barrier in front of the Aerated Static Compost bins. Currently, VTR’s project site requires a proper form of barriers for the Aerated Static Compost bins. The best choice at the site currently is a piece of metal that is tied to the bin with a small amount of string. Although this is better than nothing, wildlife have still found their way into the bins. This is a problem because compost will only heat up and break down if it is stationary. Additionally, if animals are eating the compost, it will disrupt the final volume of compost produced. With animals disrupting the piles, the readings and measurements are also compromised. Our recommendation is to create a door similar to a horse stable that has a solid latch so it is stronger, and animals will be unable to enter the bin or push down the barrier.

We recommend providing feedstock suppliers with information on categories of waste VTR is utilizing. When the feedstocks were delivered to the farm we observed that wastes are not properly separated by the categories specified by VTR. Many of them which were supposed to only contain organics had meat scraps and plastic gloves inside of the barrels. We recommend distributing an information sheet on what the different types of food wastes are, which our sponsor VTR has already created (Appendix F). In addition to this, we believe that clearly labeling the bins VTR distributes with the category of food is a critical step in ensuring the proper wastes are entering the proper systems.

We recommend determining the amount of organic waste being produced in Monteverde, Costa Rica.

An issue surrounding organic waste in Monteverde is that there is currently no accurate figure describing the amount of organic waste being created, how much is being put into landfills, or how much is available for VTR’s use. We recommend VTR establishes a running list of all of the restaurants, businesses, and hotels in the area which have organic waste that gets thrown away. We recommend performing a survey with all of those businesses, to determine the actual amount of organic waste not being utilized. The recommended questions can be found in Appendix H.

We recommend coding and analyzing the results from this survey. This analysis will indicate the actual amount of waste being put into landfills. This can be utilized by VTR to communicate with the municipality about how much they are paying to put organics in landfills that do not need to be put in, creating opportunity for them to cut costs. Creating this relationship with the municipality could potentially drive them to enforce waste separation techniques on these businesses to avoid organics from entering landfills. If organics are separated it will establish a permanent way for VTR to get feedstocks for its reactors. In addition, this will provide VTR with a number describing how much input VTR should expect per week, allowing a better projection to be made for upscaling the facility. Establishing these numbers is critical to gaining supporting for the integrated organic waste facility because it further addresses reducing the repercussions of landfills.
We recommend performing secondary level trials on all of the systems.

**Vermicomposting:**

We have concerns with the vermicomposting system that we used on the farm. The reactor does not have a good cover to keep out wildlife, which creates a problem in maintaining a worm population. The system, additionally, has a space between the bottom of the avocado crates and the green landscaping fabric which allows the worms to get stuck. This can decrease the amount of waste that is processed, and additionally creates problems removing the worms. While this setup was beneficial in early experimentation because it was cost effective, we recommend investing in a different reactor setup for running secondary trials. After performing research and understanding the materials available in Monteverde, we recommend a reactor built in 5 gallon buckets. This system is recommended because it is inexpensive to set up and does not utilize a lot of space, allowing for all of the proposed trials to be run in the space VTR has available. This system additionally addresses the problem of wildlife invasion, because 5 gallon bins come with tight lids. Set up instructions can be found in the link below.

https://www.thespruce.com/inexpensive-worm-bin-from-plastic-buckets-2540077

When performing secondary trials, we recommend performing trials which involve integration of the systems directly. In trial 2, we utilized a conservative approach by mixing the bokashi with coffee chaff and pre composted material. If this was performed on a large scale, mixing these materials will be tedious and time consuming. We recommend performing trials which use direct bokashi, and aerated static composting results without mixing them with other materials on the small scale to see if they will work. This will provide additional data on how feasible integration will be and additionally remove labor in mixing when performing on a large scale. We additionally recommend performing trials with direct food scraps and analyzing how long it will take for the worms to decompose the material. This will determine if the pre composting steps are truly necessary. We recommend comparing the results of all of these trials and determining what produces the best product.

**Aerated Static Composting:**

Due to the delay in acquiring a blower at the beginning of the project, there will not be a finished trial of Aerated Static Composting, and recommendations cannot be made based on the running trial because there is no result at this time. For future trials, we recommend testing the proposed recipes that the team created with Gerardo Calderon that we could not perform given the resources. These trials are based on a volumetric ratio of 2:1 Carbon to Nitrogen, and the aeration of these mixtures should be adequate for the Aerated Static Composting trials. If the decision is made to repeat a recipe based on the results we have, we suggest using the recipe from Trial 2 because based on the data collected, that trial was the most successful. When trial 2 was introduced to the worms they did not migrate into the mixture. The wood shavings in this mix caused a lack of moisture, and based on this we recommend using coffee chaff because it will break down better and will not diminish moisture.

**Bokashi Fermentation:**

If it is decided to utilize bokashi fermentation as a means of processing waste on a municipal scale, we would recommend first running a few more trial runs to further test the bokashi bran to food scraps ratio. Since our team will not be able to assess the outcome of bokashi fermentation trial two, we are not able to draw any conclusions on what a most desirable ratio would be. Finding this ratio is very important to ensure bokashi bran is utilized in a cost effective
manner to maximize the bokashi byproduct’s profit. Using too much bran per batch can equate to a lost profit when using bokashi fermentation in a large scale system.

**Biodigestion:**

For the trials conducted on the biodigesters, there was no methane produced in the two weeks of testing. Potential complications would be associated with the ratios of feedstocks, particularly with the manure and water. The 1:20 ratio appears to be too diluted for the biodigester to be effective. In the emails with Mr. Camacho, he said that the UGA uses a ratio of 1 kg of manure to 4 L of water, which is a considerable difference from what the VTR team used. For secondary level trials, we first recommend running experiments with just pig manure and water and focusing on trying to generate methane without any additional feedstocks. Pretreatment of the manure with the MM solution should continue, but the ratio between pig manure to water should be changed. Eventually, experiments with two different organic waste materials with adjusted ratios should be done to maximize how much organic waste can be treated. For example, in one biodigester, treatment of grease can be recreated with a 1 kg of pig manure to 10 L of water ratio to maximize the amount of bacteria and microorganisms to break down the waste and produce methane. In the second biodigester, a different feedstock such as whey or food scraps could be tested along with the increased pig manure to water ratio.

![Figure 21: The different layers of material within a biodigester (Chase, 2015)](image)

Also, within the biodigester, the effluent can actually be used as a fertilizer for plants. However, in the two biodigesters that were constructed, use of the fertilizer was not accounted for. An inlet for the feedstocks and an outlet for the biogas were only made. Within the biodigester, there are multiple layers including the biogas, organic materials, oils and fats along with the fertilizer as shown in Figure 21. Both the oils and fats and the organic material that settle on the bottom are used to help produce the biogas. With the current system, draining the biodigester can only be done through a valve on the bottom of the tank. It is also unclear what the drained material will be used for or if it will just be discarded. By simply drilling another hole and adding another pipe to the IBC tanks, the fertilizer can be extracted from the biodigester. This would also help with the maintenance of the system. This would prove to be a more efficient method of draining where the valve would only be used to drain the leftover, unused material when conducting new trials to test different types of organic waste and ratios.
4.2 Conclusions

The goal of our project was to improve local waste management techniques in Monteverde by designing an efficient multi-stage waste treatment system that produces usable resources such as enriched soil through processes including composting and biodigestion. Through our objectives we gathered information on four methodologies of treating waste then designed and performed experimental trials for each on a small scale. We provided recommendations based on our findings.

Monteverde is not yet ready to have waste collected on a large scale. Our original thought was that local restaurants and food vendors would be more than happy to give us their waste due to our assumption that waste management was a prominent issue affecting the area. It turns out that this is not the case; pig farmers and small scale composters are local competitors for using food scraps. Since these competitors have longer relationships with the restaurants, they get first claim at food scraps, making it difficult for VTR to obtain the quantity of foods scraps necessary for the business.

In general, the reactors we built were able to process organic waste and produce some results, even if it is just in the form of data or observations. The team believes that given more time, the project would have been able to see more physical results that would allow us to further determine the extent to which waste was able to be processed. Our team additionally does not believe that the experimental data we have is sufficient enough at the time to suggest the scale up on biodigestion, vermicomposting, bokashi fermentation and aerated static composting.

For vermicomposting, we were not able to see a finished product in any of the trials we set up. Until there is a finished product shown, we would not recommend building on a large scale. The large scale system our sponsor would like to utilize involves putting a large amount of worms in long bin, adding a large amount of food material everyday, and having a fork mechanism sift out final product after two months. Our team believes this fork will likely crush the worms and damage the population. The worms will also lay eggs so if they do not hatch within the time the product is harvested, the eggs will be removed with the final product. The eggs are very small so they will be sifted out and will be present in the final vermicompost. This could be beneficial for the vermicomposting, but is not good for maintaining and growing a worm population. Another issue foreseen in this system is that the worms will not eat the old material if new material is added. If given fresh new food there creates opportunity for overheating to occur or fruit flies to invade the bins, due to worms not finishing the old food (Urban Worm Company, 2018).

The biodigestion systems did not create any methane in the time span that we were in Monteverde, therefore there is no data suggesting that this system will even work the way it was set up. For aerated static composting, we were unable to complete any trials because we did not receive the blower until week five. There was a lack of data implying that the aerated system works well in the intended timeline or if works at all. For bokashi fermentation our first trial suggested that the fermentation is an effective treatment method for processing organic waste. Although these byproducts can be directly used in vermicomposting, we do not suggest using this method on a large scale system until further trials are completed to determine an ideal ratio of food scraps to bokashi bran. Due to insufficient data on all four systems, our team believes it is premature to scale up at this time.

Our team believes at this point in time that before an integrated organic waste management system can be implemented in Monteverde, additional trials on each system must be performed for longer periods of time. Conducting more small scale trials will provide a better understanding of how to optimize each of the systems. It is also unknown at this time the capacity of waste which can be processed by each reactor, except bokashi, and seeing a trial run start to finish will provide
this amount. This is critical information to understanding the quantity of upscale that needs to occur. In addition, it is important to understand the actual amount of organics that are available in Monteverde. Gathering information on the amount of organic waste thrown away by businesses that can be used in VTR’s systems will provide a figure on the size to which the system can scale. Additionally, it is still unknown whether or not the quality of the products produced by each trial is desired. The byproducts of each trial, once completed start to finish, must be sent to a lab to have the product evaluated for soil nutrients.

In conclusion, an integrated organic waste treatment facility in Monteverde has the potential to provide the community with an effective solution to manage the three current issues regarding waste; greenhouse emissions, solid waste, and waste water. However, our team believes that in general, more investment into running additional trials, and communication with businesses and the municipality is required before implementing the integrated organic waste system on a large scale. We hope that the recommendations we provided can assist with further perfecting of the individual processes and in opening up more communication between the feedstock providers to aid further success in the long term project.
References


Policy and Law; Amsterdam, 46(2), 175-185. Retrieved from https://search.proquest.com/docview/1790596898/abstract/1ED2924774EE42DDPQ/1


Cooperativa Organic Fertilizers and Bio-ferments: Improving soil health, crop productivity and quality.


Appendices

Appendix A: Interview Questions for Conversation with Experts

We are a group of students from Worcester Polytechnic Institute in Massachusetts and we are working with Vision to Reality to develop an organic waste treatment system suitable for the Monteverde region. Currently, we are conducting interviews with residents and local businesses to better our understanding of the impacts untreated waste has on the Monteverde community and how we can work to combat these issues.

Your participation in this interview is completely voluntary and you may withdraw at any time. This interview should take approximately 20-30 minutes. Please remember that your answers will remain anonymous. No names or identifying information will appear on the questionnaires or in any of the project reports or publications unless consent is given. If interested, a copy of the results can be provided through an internet link at the conclusion of the study.

Questions for anyone with a Waste Management Experts system of any form:

1. What made you want to build this system?
2. What do you gain from this system?
   1. Why did you choose this particular ‘set up’ over other options?
3. Are there any particular problems you have encountered with the system?
   1. What are the inconveniences with this system?
4. Why are you compelled to utilize this system opposed to others (ie composting, biodigestion depending on the individual)?
5. What have they learned? What solid components work best for them and how did they get to that output? – (if they have)
6. We are proposing this system (Describe the system we proposed). What flaws do you see in the proposition?
7. What ratio of the feedstock materials would you recommend using in the trials we proposed?
8. Are there any concerns/limiting factors associated with this system in Monteverde?
9. Do you have any recommendations on what you think would improve the designs?
10. What is the future potential for industrial-size reactors to treat problematic waste flows in the commercial and domestic sectors at the municipal level?
Appendix B: Interview Questions for Organic Farmer

We are a group of students from Worcester Polytechnic Institute in Massachusetts and we are working with Vision to Reality to develop an organic waste treatment system suitable for the Monteverde region. These are liaisons we are working with in accordance with Vision to Reality on this project. We are conducting interviews with a local expert in organic farming to better our understanding on how to process untreated organic waste through sustainable means of composting and biodigestion. The participation of these individuals is voluntary and they can withdraw at any time. Answers from these individuals will remain anonymous and no names or identifying information will appear in any of the project reports with permission of the individual. If interested, a copy of the results can be provided through an internet link at the conclusion of the study.

Organic Farmer:
1. Have you ever used vermicomposting, aerated static composting, bokashi fermentation or biodigestion as a means to improve soil conditions?
   a. If yes - how?
2. What are the soil conditions are most desirable in Monteverde in terms of carbon and nitrogen?
   a. Do you foresee the trials we proposed to create these conditions?
   b. If not- why?
3. In terms of the individual reactors, do you see any flaws in how we propose to run them individually?
4. Do you think have thoughts the trials we proposed in terms of integrating the systems?
   a. Do you see any major flaws or concerns?
Appendix C: Flowchart for Proposed Integration of Composting Primary Level Trials

Key:
ASC- Aerated Static Composting
LC- Vermicomposting
EMH- Additional trials of seedlings to be performed at a later time by Gerardo Calderon
Arrows- Show where outputs from each trial go and how systems were incorporated into each other.
Appendix D: Vision to Reality Reactor Protocols

**Vermicomposting:**

*To begin Vermicomposting Bins:*
1. Spread a thin layer of paper shavings on the bottom of the vermicomposting bins, enough to cover the bottom.
2. Moisten paper with enough water to create a damp environment. Do not allow any water to pool at the bottom of the bin during this step.
3. Add worms and feedstocks accordingly
4. Cover top layer with a piece of cardboard

*To maintain Vermicomposting Bins:*
1. Check daily for moisture content, ensure there is no dry material in the bins
2. Add additional feedstocks as desired

**Aerated Static Composting:**

*There are five composting bins created out of pallets. After the feedstocks are mixed on the ground and added to the bin the time frame of composting is ready to start.*

*To collect data from each bin do the following:*
1. At an angle insert the thermometer into the first pile and leave it there until the pile is done moving. Record the temperature.
2. Then Insert the pH and moisture probe
   a. With the switch to the pH scale record the pH
   b. With the switch to the moisture scale record the moisture
3. Take a hand full of the compost and smell it
   a. Rate the odor strength 1-3 (1=No Odor and 3=Strong Odor)
   b. Rate the odor category 1-3 (1=Compost, 2=original, and 3=Purification)
4. Record all this data and repeat for the other bins
5. After all data is gathered turn each pile (turn the blower on for 20 minutes for each pile)

![Figure 22: Meters for Aerated Static Composting Protocol](image)
Bokashi Fermentation:
Using a Bokashi Fermentation barrel (an airtight barrel with a spigot and a burper).

1. Place a layer of bokashi bran that completely covers the bottom of the barrel (about 2 handfuls)
2. Then place chopped up food scraps into the barrel (roughly 3-5 gallons of scraps)
3. Spread the chopped up food scraps evenly and use a flat surface to compress it towards the bottom of the barrel
4. Once the flat surface is compressed, cover the scraps with another layer of bokashi bran until the food scraps are completely covered
5. Repeat steps 2-4 until the barrel is full or the feedstock is depleted
6. Once finished with step 5, seal the barrel and let it sit for two weeks
   a. Drain liquid from the barrel using the spigot daily
   b. Ensure the burper does not let in any unwanted oxygen

Biodigester:
The two IBC tank biodigesters are connected together through PVC, with tubing attached to a burner. From the location of the burner, Biodigester 1 is on the right and Biodigester 2 is on the left. The key valves are left open so unwanted gas build-up does not occur within the biodigester.

1. To test Biodigester 1, close the key valve to Biodigester 2 and leave open the key valve to Biodigester 1.
2. With the burner, slowly turn the knob to allow the gas to flow out the burner.
3. Take a lighter and light the top of the burner.
4. If a flame is produced, monitor how long the flame is able to burn for.
   a. Record the time until there is no flame.
   b. If no flame is produced, no methane is being produced.
5. Record all results & observations.
6. Once testing of Biodigester 1 is complete, turn the burner off.
7. To test Biodigester 2, first close the key valve to Biodigester 1 and open the key valve to Biodigester 2.
8. Repeat steps 2-6 for Biodigester 2.
Appendix E: Data Charts For Aerobic Compost

Key
Odor Strength: 1 = No Odor, 2 = Mild Odor, 3 = Strong Odor
Odor Category: 1 = Composted Material, 2 = Original Material, 3 = Putrefied Material
Moisture readings were taken, however it is unknown at this time what it means.

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Data for Trial 5 (this trial was dismantled so no further testing will happen)

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### Appendix F: Classes of Restaurant and Supermarket Waste

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</table>
| 1        | Select Kitchen Waste & Expired Produce (SKWEP):  
All vegetable and fruits except pineapple and citrus | ● Vermicompost  
● Aerobic compost |
| 1        | Non-select Kitchen Waste (NoSKW)  
Citrus, egg shells, large seeds, pineapple peel and crown, dairy, bones and fats | ● Aerated compost  
● Vermicompost  
(with pre-treatment) |
| 2        | Dining Room Waste (DRoW)  
Cooked food  
Bones/fats  
Napkins | ● Fermentation  
● Aerated compost  
● Vermicompost  
(with pre-treatment) |
| 3        | Grease Trap Material (GTM)  
Fat layer  
Watery/liquid layer  
Precipitated solids | ● Biodigestion  
● Aerated compost  
(solids) |
| 4        | Pig Manure (proxy for Septic Sludge) | ● Biodigestion |
| 5        | Waste Vegetable Oil (WVO) | ● Biodiesel, etc. |
## Appendix G: Catie Soil Labs Price Sheet

### LABORATORIO DE ANALISIS DE SUELOS, TEJIDO VEGETAL Y AGUAS.

**Lista de Precios 2015**

<table>
<thead>
<tr>
<th>CÓDIGO</th>
<th>DESCRIPCIÓN DEL ANÁLISIS</th>
<th>PRECIO ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SQC</td>
<td>Análisis químico completo (pH, acidez ext., Ca, Mg, K, P, Cu, Mn, Zn, Fe)</td>
<td>14.5</td>
</tr>
<tr>
<td>SQS</td>
<td>Análisis químico sencillo (pH, acidez extraible, Ca, Mg, K, P)</td>
<td>11</td>
</tr>
<tr>
<td>SNT</td>
<td>Nitrógeno Total</td>
<td>7</td>
</tr>
<tr>
<td>SCO</td>
<td>Carbono Orgánico</td>
<td>8</td>
</tr>
<tr>
<td>SCT</td>
<td>Carbono Total</td>
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</tr>
<tr>
<td>SCT+SNT</td>
<td>Carbono Total+Nitrógeno Total</td>
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</tr>
<tr>
<td>SCIC</td>
<td>Capacidad de Intercambio Catiónico (C.I.C. y Bases)</td>
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<tr>
<td>SOXA</td>
<td>Hierro y Aluminio en Oxalato</td>
<td>12</td>
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<tr>
<td>SNAM</td>
<td>Nitratos y Amonio/KCl 2M</td>
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<tr>
<td>SRPZ</td>
<td>Retención de Fósforo (Nueva Zelanda)</td>
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<tr>
<td>SPT</td>
<td>Fósforo Total</td>
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<tr>
<td>STXT</td>
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<tr>
<td>SDA</td>
<td>Densidad Aparente</td>
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<tr>
<td>SDP</td>
<td>Densidad de Partícula</td>
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<td>SRHP</td>
<td>Retención de Humedad por presión</td>
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<tr>
<td>SCH</td>
<td>Contenido de Humedad</td>
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<tr>
<td>SCE</td>
<td>Conductividad eléctrica (pasta, disolución)</td>
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<tr>
<td>SPH</td>
<td>pH (H2O)</td>
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<tr>
<td>SKPH</td>
<td>pH (KCl o NaF)</td>
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<tr>
<td>SKAL</td>
<td>Acidez Intercambiable (Al)</td>
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<tr>
<td>SIND</td>
<td>Elemento individual de SQC</td>
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<tr>
<td>SCO2</td>
<td>Determinación de CO2 por titulación</td>
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<tr>
<td>SBM</td>
<td>Determinación de Biomasa Microbial</td>
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<tr>
<td>SIANA</td>
<td>Incubación Anaeróbica</td>
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### ANÁLISIS DE TEJIDO VEGETAL

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<th>PRECIO ($)</th>
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</thead>
<tbody>
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<td>FS</td>
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<td>ANALISIS DE ABONOS</td>
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<td>--------------------------------------------------------</td>
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<td>ABQC</td>
<td>Análisis de Abono completo (P, Ca, Mg, K, Cu, Zn, Mn, Fe, %Humedad)</td>
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<td>Análisis de Carbono Total + Nitrógeno Total</td>
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<td>ABH</td>
<td>Contenido de % Humedad</td>
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<table>
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</thead>
<tbody>
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<tr>
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<td>Análisis de Dureza</td>
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<td>ALK</td>
<td>Análisis de Alcalinidad</td>
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<td>ACI</td>
<td>Análisis de Cloruros</td>
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<td>ANIT</td>
<td>Nitrato (N-NO3−)</td>
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<td>AAM</td>
<td>Amonio (N-NH4+)</td>
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<td>AS</td>
<td>Azufre</td>
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<td>AST</td>
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<td>AIND</td>
<td>Elemento Individual del AQC (Cu, Zn, Mn, Fe, Ca, Mg, K, Na)</td>
<td>8</td>
</tr>
</tbody>
</table>

Rige a partir del 01/05/2015.
Horario de recepción de muestras:
Lunes a Viernes de 7:00 am a 11:30 am y de 12:30 pm a 4:00 pm.
La cancelación de los análisis se realiza en la Caja Central del CATIE al ingreso de las muestras.
Teléfono 25582377. Fax 25563018.
Apartado postal CATIE 7170, Turrialba, Costa Rica.
Dirección electrónica: pleandro@catie.ac.cr.
Appendix H: Survey Questions for local Businesses on waste contributions

1. How much waste do you produce weekly?
2. Out of that waste, how much of it is organic waste?
3. How do you currently dispose of it?
4. Do you know where your waste goes after it is disposed?
5. What are the costs associated with waste disposal?
6. Would you be interested in bringing your waste to a central facility if it provided increased benefits (of some determined options)?
   a. How far would you be willing to travel?
   b. How often would you like to bring waste there?
   c. Do you have your own transportation method?