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John Hemmerling

Purdue University, jhemmerl@purdue.edu

Jeremy Pan

Purdue University, pan117@purdue.edu

Sahil Bhalla

Purdue University, bhallas@purdue.edu

Karan Kedia

Purdue University, kkedia@purdue.edu

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REDUCING LANDFILL WASTE:

Implementation and Optimization of a Vermicomposting System

John Hemmerling, College of Engineering, Jeremy Pan, College of Science, Sahil Bhalla, and Karan Kedia, College of Engineering

ABSTRACT

John Hemmerling, a senior in chemical engineering and project leader, Jeremy Pan, a sophomore in computer science, and Sahil Bhalla and Karan Kedia, both freshman in first-year engineering, are a team of four students participating in the Engineering Projects in Community Service (EPICS) Environmental Improvement Initiatives (EII). In this article they describe how they are investigating waste generation reduction at the Retrofit Net-Zero Energy Water and Waste (ReNEWW) house in West Lafayette, Indiana, in conjunction with Whirlpool Corporation. Their work is intended to provide guidance to households on implementing vermicomposting systems so food waste can be diverted from our landfills.

INTRODUCTION

Waste production strains the limited natural resources of earth and indicates an inefficient use of resources. Transporting waste to a landfill is also energy intensive. Additionally, landfilled waste can have negative effects on the environment, for example, hazardous waste and chemicals can leach into surrounding soil and groundwater. On a smaller scale, waste still poses problems. In 2012, Indiana's municipal solid waste totaled 1 ton per person per year and consisted of 29% paper, 17% plastic, 10% food waste, 7% yard waste, 7% wood, and 6% metal (Abramowitz, 2012). Paper, plastic, and metal can be recycled, while wood, food waste, and yard waste can be composted, thus reducing the amount of trash sent to landfills.

A team of four Purdue students on the Engineering Projects in Community Service (EPICS) Environmental Improvement Initiatives (EII) team are investigating various ways to reduce waste generation at the Retrofit Net-Zero Energy Water Waste (ReNEWW) house located at 545 Hayes Street in West Lafayette, Indiana. The project is a part of the EPICS program, which provides opportunities for students to complete real-world engineering projects in the community. The team has received weekly feedback from Dulcy Abraham (Professor of Civil Engineering at Purdue University), Furman Smith (retired chemical/environmental engineer), and Steve Leeper (practicing chemical/environmental engineer).

The team implemented a vermicomposting bin system to divert compostable materials from a landfill. Vermicomposting utilizes red wiggler worms to break down newspapers, cardboard, coffee grounds, egg shells, and plant-based food waste; it excludes meat and dairy products. Worm cast (fecal matter) results in highly nutritious soil. Compared to normal soil, casts contain eight times as many microorganisms as their feed, five times more nitrogen, seven times more phosphorous, and eleven times more potassium (Addison, 2015). Other benefits of vermicomposting include low installation cost, low maintenance, and increased safety. The vermicomposting bin system can also be placed indoors, which is more convenient for residents.

The Whirlpool Corporation sponsors the project and currently leases the ReNEWW house from the Purdue Research Foundation. Whirlpool is investing capital in the ReNEWW house to demonstrate projects that reduce

water, energy use, and waste generation, with an ultimate goal of achieving a house that is net-zero water, waste, and energy. Whirlpool ultimately wants positive results from the ReNEWW house to demonstrate their commitment to the environment. Todd Graham—a graduate student in mechanical engineering at Purdue University, Whirlpool employee, current resident in the ReNEWW house, and project contact—provides consultation to the team before they make major decisions that affect the project stakeholders. By working closely with residents of the ReNEWW house, the team has received constant feedback regarding the effects of the vermicomposting bin on their lifestyle, and has taken these observations into account while adjusting the design and implementation parameters of the system. Overall, the Whirlpool engineers residing in the ReNEWW house were well prepared to work with the team throughout the project. The residents were a source of collaboration and they provided adequate space and tools to develop, implement, and test the vermicomposting bin system. The residents also separated compostable food waste from other trash and utilized the vermicomposting system, thus facilitating the process of eliminating waste sent to a landfill.

METHODOLOGY

Trash Audits

Four weeklong trash audits were performed between January and March 2016 to evaluate and quantify garbage, recycling, and food waste produced by residents of the ReNEWW house.

To conduct the trash audit, the team set up three trash cans to separate the waste in the following categories:

- Garbage: material that is not recyclable or compostable and is currently sent to a landfill. Noncompostable foods include citrus, dairy, meat, and bread.
- Recycling: reusable material, as is or with treatment, that is acceptable for curbside pickup or delivery to a recycling center.
- Compostable: material that can be composted by the vermicomposting system, including cardboard, newspaper, tissue paper, paper towels, and food (with exceptions listed above, e.g., citrus, dairy, meat, and bread).

Each trash can used in this study was weighed. After about one week of material collection, the team verified that the categories of waste were separated correctly and determined the mass of trash generated by reweigh-

ing each trash can and subtracting the weight of that trash can. Each waste category was further divided into subcategories to determine specific items that might have the largest potential effect on waste reduction strategies. For example, the garbage category was divided into several subcategories including food packaging, paper towels, and electronics. Three additional trash audits were performed to determine the variability and reproducibility of the results.

Initialization of the Composting System

One pound of red wiggler worms, or roughly one thousand worms, was purchased online for \$20. The vermicomposting system was constructed using two 20-gallon bins (example bin shown in Figure 1). One-sixteenth-inch diameter holes were drilled every inch around the top half of both bins to increase airflow through the bins. One-quarter-inch diameter holes were also drilled at the bottom of the top bin to allow for worm migration between the two bins. When developing the initial bin, there were several unconfirmed measurements, but the team obtained more precise details during the setup of the second bin. The bedding consisted of ripped, corrugated cardboard and newspaper with black ink; colored inks contain chemicals that can harm the worms, and hence should not be used in vermicomposting systems. The use of 30 ounces of corrugated cardboard and 6 ounces of shredded newspaper provided enough material to create a 4-inch deep bedding to begin the composting process. Mixing the bedding well with 1.5 liters of water was necessary to create a sufficiently damp environment for the worms, as they respire through their skin.

Selecting the proper food to add to the bin is integral in keeping the bin environment optimal for the worms. The team added fruits and vegetable scraps, both beneficial

Figure 1. Example bin for composting setup.

for consumption by the worms, and coffee grounds and eggshells for pH control. The bedding material, composed primarily of cardboard and newspaper, also includes items that the worms consume well. The team experimented by adding tough-to-decompose items such as stems of broccoli and determined that the material was too hard for worms to eat easily. Thus, tougher foods were cut into very small fragments before incorporating them into the bin. No meat, cooking oil, fats, dairy, grain, or citrus were added, as the worms struggle to consume the material; further, those food items have the potential to attract unwanted attention from insects like fruit flies.

Optimization

Since maximizing the waste reduction potential of the house was the overall goal, the team looked to further improve the vermicomposting system to handle more compostable material. Throughout the fall 2015 semester, several problems, such as the introduction of mold and the smell of rotting food, were observed in the vermicomposting system since the worms did not decompose all of the food the team supplied the prior week.

To ensure that all the food added to the bin is decomposed by the worms, optimal conditions should be maintained inside the bin. The team mixed the compost every week after adding the food waste to aerate the bin and promote relative uniformity of food throughout the bin. To maximize the rate of decomposition, several factors contributing to the environment of the worm bin were measured, which included temperature, moisture, and pH. The ideal temperature range for the worms is 55 °F to 80 °F (Donaldson, n.d.). The team measured the temperature using a soil thermometer (Manufacturer: AcuRite, ASIN: B000FDB BG4) at three different depths for three different locations every week to verify the relative uniformity of temperature throughout the bin. The evaluated locations had an average of 70 °F, well within the optimal temperature range needed by the worms (the worms can survive in temperatures between 32 °F to 95 °F). Additional bedding can serve as insulation during the winter to maintain the necessary temperature range. Any temperature range above 80 °F or below 55 °F may not produce optimal results. Therefore, it is imperative to provide temperature conditions well within the optimal range.

Moisture content is another vital parameter. The team used a soil moisture meter (Manufacturer: Mudder, ASIN: B00 W2Z ROT6) to quantify the amount of moisture present in the compost, measured on a scale from

1 (dry) to 10 (moist). Since worms respire through their skin, a wet environment is always required for them to survive, a higher measurement on the scale is desirable, and a moisture rating of 8 out of 10 is ideal. As with the temperature levels, the moisture readings were taken from three different locations at three different depths (same every week) in the bin to ensure uniformity, which was found to have an average of 8.5 out of 10, which is in close proximity to the ideal moisture rating.

A third important parameter is pH, which changes in response to the different types of food added to the bin, the temperature of the system, or the metabolism of the worms. The ideal pH range is 6 to 7, with a pH of 6.5 being the most desirable (Worm Man, 2016). The team utilized the pH-measuring capacity of the soil moisture meter (which measures between the pH ranges of 3.5 and 8) to take pH measurements around the bin, finding that the pH levels throughout the bin remained relatively constant at 7.5 over several weeks. These measurements indicated that the pH was on the higher side of the recommended range (6 to 7), so several options were found to adjust the pH. Aerating the compost removes any excess carbon dioxide from the system. Carbon dioxide and water form carbonic acid, which is responsible for lower pH levels. Manual aeration helps release this carbon dioxide to increase the pH levels, while adding products like egg shells reduces pH levels. Another method of changing the pH includes adding elemental sulfur, which can quickly increase the acidity of the system.

Since food waste serves as the feed to the composting process, the feed rate must also be studied to determine the optimal compromise between the quantity of food converted and the rate of food conversion. Under the optimal conditions described above, worms are able to eat roughly half their weight in food in a day. One pound of worms (starting point for the implemented bin vermicomposting system) translates to consumption of one-half of a pound of food a day or 3.5 pounds of food in a week (Bentley, 2009). To maintain this rate of composting, the worms were fed roughly four pounds of food per week. The worms use a small portion of the material they consume to grow, while the rest of the material is directly converted to compost material. Since the worm bin has been active since November 2015, the number of worms has undoubtedly increased. Counting the number of worms present in the compost bin allows for a rough estimation of how much material the worms can digest in a week. The team estimated the number of worms using a sampling technique. The bin was divided into 16 equal-sized squares, and the worms were counted

Figure 2. Waste reduction plan from vermicomposting system.

in one of these squares. Assuming uniform distribution of worms, multiplying the number of worms counted in this square by 16 allows for the estimation of the total number of worms in the bin. The number of worms was estimated to be 2,700. Assuming that 1,000 worms weigh about 1 pound total, the team estimated that 2.7 pounds of worms are present in the bin, and they can consume approximately 1.3 pounds of food per day. Maintaining optimal temperature, pH, and moisture levels allows the worm bin to process the maximum amount of food and increase decomposition, which in turn improves overall efficiency. Underfeeding and overfeeding can kill the worms, reduce their productivity, and lead to mold growth. This is detrimental to the compost bin environment; a proper environment will increase reproduction rates (Urban Worm, n.d.). Maintaining the optimal conditions will enable the vermicomposting system to handle as much material as possible, and in turn maximize waste reduction.

RESULTS

Throughout the project, the primary measurement of success was the overall reduction of waste sent to a landfill. Based on trash audit results, the vermicomposting system originally resulted in a total landfilled waste reduction of 36%, as shown in Figure 2. Additionally, the optimized vermicomposting system can reduce the amount of waste sent to a landfill by 56%.

A breakdown of all materials sent to a landfill after implementing the vermicomposting system is shown in Figure 3. Even with the vermicomposting system, a large percentage of landfilled waste still consists of paper towels and food waste because more compostable material was generated than the vermicomposting system could decompose.

As shown in Figure 4, the original vermicomposting system composted about 64% of all compostable material produced in the ReNEWW house. The bulk of the noncomposted material consisted of paper towels. While paper towels can be composted in small quantities, large

amounts of paper towels can result in aeration problems and can take a while to be decomposed.

By optimizing the vermicomposting system, the remaining 36% of compostable material can be composted rather than being sent to a landfill. Since the number of worms has increased and the worms live in an optimal habitat, all of the food and paper towels can be composted, resulting in a total landfilled waste reduction of 56%, as illustrated in Figure 2.

IMPACT AND CONCLUSION

To date (April 2016), the implementation of a vermicomposting system has diverted about 64% of compostable waste generated at the RenNEWW house from a landfill. However, since the worm population has increased and the worms are living in optimal conditions, diversion of compostable waste can approach 100%. By implementing a composting system that composts 100% of compostable material, the amount of waste sent to a landfill can theoretically be reduced by 56%. As the results explain, the vermicomposting system has had a large impact on the amount of waste sent to a landfill by the ReNEWW house. The team has documented all of the details for implementing and optimizing a vermicomposting system, so other families in the community that would like to divert waste from a landfill and produce compost for a garden can use this model.

The Whirlpool ReNEWW house project provided an excellent opportunity to all team members for developing technical, professional, and leadership skills. Key lessons learned by the team include: (1) integrated design and implementation of a vermicomposting system, (2) methods for optimizing the performance of the prototype vermicomposting system, and (3) the importance of close engagements with stakeholders (in

Figure 3. Landfilled waste categories.

Figure 4. Percent of compostable material actually composted by the vermicomposting system.

particular, the residents of the ReNEWW house). Perhaps the most important skill learned was how to start with an open-ended problem and determine the best ways to solve that problem. The team was adequately prepared to complete all necessary tasks and tackle the issue. However, prior knowledge on some relevant topics would have been very beneficial for the overall efficiency of the team. Preparation can be improved if students have some prior knowledge of vermicomposting, which can have a positive effect on the project.

The skills gained in this project are treasured by the whole team, as these skills are typically not acquired in traditional courses. Every member of the team believes that the knowledge gained from this project can benefit the people around them and the community as a whole. Working as a team on this project has helped them gain valuable experience and important technical skills that affected the environment for the better. If the project is continued, then the vermicomposting bin will be continuously upgraded and other ways to eliminate waste in the ReNEWW house will be pursued. In the case that Whirlpool decides not to continue the project, the team

has developed a vermicomposting brochure that documents the information required to maintain the system for the upcoming years. The compost produced can be used to grow plants in a garden outside the ReNEWW house. The vermicomposting bin has not only helped us reduce trash sent to a landfill, it has also enabled us to do something productive for the environment—reduce the trash sent to a landfill.

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