Development of a food waste composting system using Black Soldier Fly larvae

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Problem Statement

The management of food waste has increasingly become a concerning topic in the field of waste management and environmental conservation. In the US and other developed economies, food waste is generally diverted to landfills, incinerators, biodigesters or composting facilities. However, around 96% of the total food waste in the US ends up in landfills or incinerators [1]. Anaerobic decomposition of food waste in landfills releases high concentrations of methane – a potent greenhouse gas (GHG). As concern about landfill space increases, worldwide interest in additional end of life options is growing. In the case of food waste, biodigesters and composting processes are attractive alternatives since decomposable organic materials can be converted into useful products [2].

Only one of the dining venues in Rochester Institute of Technology's (RIT) diverts a fraction of food waste to a facility for processing in an anaerobic biodigester sending 1.5 - 2.0 tons on a weekly basis, or as much as 200,000 lbs. over the course of a year. Biodigestion is performed in an off-site facility to a limited scale as this cannot intake fibers (paper cups, paper plates, napkins, etc.) – which are highly present in post-consumer wastes. For alternative low-cost composting methods, such as windrow composting, there are regulatory and legal limitations that restrict an on-campus implementation. It is of our team's interest to explore creative solutions to address the dire implications of the current Food Waste Management (FWM) practices and its repercussion to the environment. This project explores the feasibility of implementing a food waste composting system using Black Soldier Fly Larvae (BSFL). In addition, this research examines and quantifies the environmental and economic performance associated with the FWM system currently used and the proposed composting alternative.

Introduction and Background

Composting with worms and grubs is a known method of organic waste treatment commonly used in rural areas, generally in regions with high agriculture and livestock activities. Although the use of earthworms is a common practice in food waste composting, grub composting presents an innovative and less restrictive approach. The use of BSFL in grub composting has been documented in literature recently although being practiced informally and unstandardized across the world for many years. This species of fly, Hermetia Illucens, is indigenous across the continent of America, being found from Australia to Colombia and across the United States [3]. The larvae spend the majority of their lifetime feeding on organic waste and turning it into fat, protein and calcium to morph into pupae, and later, into adults. In their adult phase, BSF do not have functional mouthparts; therefore they do not bite nor feed, and consequently, are not associated with transmission of diseases.

Figure 1. Mapping of locations where grub composting with Black Soldier Fly Larvae is practiced around the world. The icon  is used to indicate these locations. [3]

BSFL are known for their ability to feed on a wide variety of organic waste, including: vegetables, fruits, meat, and manure. This skill gives BSFL composting distinct advantages over traditional composting, which cannot generally accept meat or dairy products and in some instances post-consumer waste. Solids and fluids exit the larvae as it digests and morph into pupae, and these can be collected and applied to the soil and useful natural fertilizers.

Literature Review

The literature explores alternative FWM largely focusing on anaerobic digestion and composting. Regarding composting, many researchers have placed attention on improving efficiency, reducing operating cost, and quantifying environmental impacts. Approaches for characterizing the environmental implications of both composting and anaerobic digestion systems include experimental design and Material Flow Analysis. In the literature, major components of gas emissions involved in composting are well-known GHG notably carbon dioxide CO_2, nitrogen oxides N_xO and methane CH_4 [4]. A cooperative study from academic and municipal institutions in Italy and Greece [5] identifies the sensitivity of the environmental impacts of aerobic composting in terms of the management practices for maintaining aerobic conditions (energy and land space) and their potential offsets (fertilizer) while anaerobic digestion systems are sensitive to the amount of methane which is produced for use as energy offset.

T. Barry [6] presented an evaluation of the economic, social, and biological feasibility of converting food waste from a campus cafeteria using BSFL concluding the range of temperature and humidity for optimal performance, as well as a range of suitable levels of texture, viscosity, and moisture content of the diet. In addition, these results confirm the ability of BSFL to consume diets with fat contents. This is an important finding because common worm composting is limited to a non-oil vegetarian diet. Thus making the grub-composting with BSFL more flexible than other composting process in terms of the type of food that can be processed.

Relationship to Sustainability

The concept of waste is common in many systems, especially in the built environment. Looking at different manmade systems, unwanted or underused materials are output without further use or value, thus resembling input-output linear systems. On the contrary, natural systems do not generate what is known as "waste" as outputs from one species acts as an input for another (i.e.: cattle feed on grass, while the grass benefits from the nutrients in the cattle's manure). Sustainability is more likely to be achieved by integrating closed loop systems were materials and nutrients flow between these, sharing benefits and symbiotic endurance. As the number of students admitted to RIT increases, food demand and waste volumes also increases. Utilizing BSFL for composting provides a means to integrate a cycle similar to that of natural systems.

Using BSFL as an alternative for food waste disposal has the potential to bring environmental and economic benefits. These benefits include reduced GHG emissions from avoided landfill emissions, decreased commercial fertilizer usage, decreased water use, increased soil carbon storage, and decreased soil erosion. The use of solids and fluids from the compost can help decrease RIT's reliance on outside vendors for artificial fertilizers or costly natural fertilizers. Moreover, the economic and environmental costs from the transportation of tons of food waste to a landfill and an off-site anaerobic digester would be reduced. In summary, RIT Dining Services, and consequently RIT as an institution, has the potential to decrease their environmental impact and operational costs associated with transporting and overall management of food waste. In a larger scale, grown fattened larvae could be distributed as feedstock -for chicken, pigs, fish- in local farms, thus reducing transportation of processed feedstock for farm animals. This in turn, could increase the yield of local farm animals and their byproducts and therefore reduce the need to transport these from potentially distant locations. In this manner, it is possible to close the loop and keep valuable nutrients within a cycle.

Materials and Methods

For the scale and scope of our project, an experimental approach is well suited to provide the answers that motivated this research. A pilot study was conducted by structuring a small scale composting cell to intake food waste from the largest on-campus dining venue. The cell is composed by a commercial composting unit “Protapod” [14], commercially available BSFL [15], food waste sourced from an on-campus dining facility, a conditioned space in the Greenhouse of the College of Science, and other supplementary tools (scale, buckets, burlap, others). A layer of gravel is used to improve aeration inside the compost unit and to help the drainage of the fluids produced by the composting process. Layers of burlap and landscape fabric are used to provide darkness and protection, and retain humidity of the compost.

In order to properly size a composting system, first, the processing capacity must be determined. Samples of food waste (kg) and exact quantities of larvae (hand counted and weighed) were used to determine rate of consumption (kg/week). By determining the amount of waste (kg) the system is able to process within the feeding phase of the larvae (days) it will be possible to estimate, by extrapolation, the required larvae density to process a fixed daily input of food waste. A schedule was designed to program periodic monitoring of the composting cell and process sheets were released for data record and analysis. A representative from Prota™Culture and faculty from the College of Science were consulted to provide insight and feedback on well-known working practices for growing a BSF colony. The composting unit acquired is designed such that it facilitates the separation of larvae and pupae. A parcel of pupae is kept for breeding purposes to ensure sustainability of the population density of the colony.

Key milestones and project tasks[1]

The project phases can be mainly categorized as planning, building, and monitoring the composting system. The key milestones of the project are outlined as the following:

i. Determining the materials and equipment required to operate the composting system
    - After careful and broad research in the literature and commercial vendors on alternative composting mechanisms, a list of all the required materials is finalized.
ii. Identifying the location
    - A greenhouse, which is located on campus, is chosen to set up the composting system due to suitable ambient conditions.
iii. Purchasing the materials and equipment from local and online suppliers.
iv. System set-up in location.
v. Determining the schedule and logistics for food waste pick up.
    - The largest dining venue on campus, which provides a wide range of food, was selected to ensure continuous supply and variety in the food waste. In addition, the location was suitable due to the mutual interest of the management and the project team to reduce food waste.
vi. Creating documents for monitoring and data collection.
    - Specific metrics were identified to quantify, analyze and interpret how the system operates.
vii. Initiating a larvae colony and adding food waste to the composting unit
    - The first batch of larvae purchased consisted of 600 larvae. The first batch of food waste contained on 14.08 lbs. vegetable and fruit mix.
viii. Monitoring the composting system status with scheduled visits

Results, Evaluation and Demonstration

The experiments conducted are considered inconclusive as the system was unable to sustain a colony of larvae. Since the maturation of the larvae and feeding capabilities take longer than estimated, more time and trials are needed to complete this research. A series of three colonies[2] have been attempted to develop so far. Notable observations:

Attempt #1: Fruits and vegetables were inputted in the ProtaPod. Larvae seem to remain active during the ~3 days in the unit but ended up crawling underneath the food and gravel. More layers

[1] Some of these tasks were initiated in parallel while others were subsequent to the completion of others as a prerequisite.
[2] Colony density ranged from 500-700 larvae.

of fabric were added to increase darkness in the unit. In addition, the team increased food variety.

Attempt #2: Fruits, vegetables, and baked goods were inputted in the ProtaPod. Larvae seem to remain active during ~5 days of being placed in the unit then crawled underneath the food and gravel. It was considered that the larvae were unable to crawl back to the surface after moving under the food and gravel. As a measure, a parallel colony was started in another container without gravel. Later on, three mature pupae were identified in the original setup and moved to a breeding unit.

Attempt #3: Baked goods and fatty proteins were inputted into the parallel colony. Larvae seem to remain active within ~3 days, but inactivity is observed to decrease. The team suspected that moisture affects this greatly. And thus, the moisture level is kept constant by increasing the frequency of water spraying. A layer of soil was placed before adding the larvae and the food mimicking a more natural habitat.

Figure 2. Larvae interacting with food upon initiating the colony.

Figure 3. Diet variety inputted to the unit. Above shows Attempt #1 and bottom shows Attempt #2

Due to the lack of data obtainable from the experiments at this point, calculations presented are theoretical. For this analysis, a comparison of both systems is useful:

Current food waste management system[3]:

Table 1. Cost breakdown of current system

Item	Unit
Waste (includes food waste, wax cardboard, paper cups)	2.5 - 3 tons
Food Waste diverted	1.5 - 2.0 tons
Distance from RIT to Biodigester	40 miles
Emissions from transport[4]	
CO	3,575 g/yr.
NOx	15,539.7 g/yr.
PM_{10}	399.4 g/yr.
Emissions from biodigester CH_4[5]	753.23 m^3/ton
Emissions from landfilled waste CH_4[6]	81.25m^3/ton
Emissions from landfilled waste CO_2[6]	43.75m^3/ton
Waste hauling to biodigester	$ 86/ton
Waste hauling to landfill	$ 65/ton

Proposed food waste management system:

The capacity of an active ProtaPod is measured in weight of waste processed per surface area over a given period of time. A volume of 3 lbs./ft^2.d of food waste is approximately 25 lbs of waste consumed daily. The largest dining facility on campus creates approximately 2 tons of organic waste weekly. This is approximately 572 lbs. per day. Based on a ProtaPod's estimated capacity to process 25lbs. of waste per day, a maximum required quantity of 28 containers should be incorporated to maintain a regular daily input of food waste. However, a backup inventory of food waste should be considered due to uncertainties in volume of daily food waste. Reasonably, for a one-day backup inventory, the size of the system could then be reduced to 14 containers.

3 Disposal alternatives and volumes are corresponding to one specific of the many dining venues at RIT.
4 Corresponding to the usage of 1 type VII diesel vehicle [16].
5 Corresponding to EPA report on anaerobic digestion of food waste. Parameter based on dry matter. [19]
6 Estimated for landfills in US and Canada [18]

(i) Economic metrics:

Given these assumptions, below is a list of initial and maintenance requirements for the system:

Table 2. Cost breakdown of proposed system

Item	Qty	Unit Cost	Total Cost	Frequency
ProtaPod	14 units	$450.00	$6,300.00	One time
Maintenance supplies	14 units	$100.00[7]	$1,400.00	6 months
Waste transport - Manpower	1 person	$20.00[8]	$140.00	7 hr./week
Waste transport - Fuel (diesel)[9]	1 gal	$4.00	$4.00	weekly
Env. maintenance (tempt. and humidity)	89,600 sq.ft[10]	$3.87/sq.ft	$346,752	annual

Given the 0.05 compost efficiency rate estimated by the ProtaPod supplier, an approximate amount of 28 lbs. of compost residue could be produced from the daily waste load. The price retail price for compost and soils ranges between $3-15 for a 25 lbs. bag, meaning it could potentially represent minimum revenue of $23.52 per week or $1,223.04 per year. Similarly, an estimate of 5 quarts of effluent per day can be collected from compost fluids. Diluted with water, an estimate of 10 quarts of effluent could be produced per day. A quart of liquid fertilizer retails between $10 and $25, resulting on minimum savings of $100 per week or $5,200 per year.

Given these estimations, we can conclude that the initial investment for the proposed system would be estimated at $7,700 while maintenance cost per year would be around $355,000, mostly due to the energy cost associated with providing the appropriate conditions to the space required to site the system. The estimated savings or revenue from compost and fertilizer production could cover up to 83% of the initial investment for the first year, and contribute about 2% of the maintenance costs for the consecutive years. Compared to the current system that

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[7] Based on the supplies needed for one ProtaPod while conducting experiment

[8] Salary estimated by Facilities Management Services at RIT

9 2 mile daily commute (round trip) on an already owned Ford F-150 type vehicle owned by Facilities Management Services at RIT. Average cost based on historic data subtracted from *http://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_nus_w.html*

[10] Estimate of the required area for 14 ProtaPod units with dimensions of 44in diameter with a 34in work area.

comes to an estimated $7,280 per year, an improvement in the efficiency and environmental benefits becomes the main purpose for the implementation of a BSFL composting system.

(ii) Environmental metrics:

The environmental profile for the proposed composting system can be analyzed from 3 sources: transportation, processing, and food waste diverted. Emissions from transportation[11] are far less in terms of vehicle sizing and distance traveled compared to the current system. For the transportation logistics of food waste from the dining venue to the Greenhouse can result in yearly averages of 87.3g of CO, 321.2g of NOx, and 10.3g of PM_{10}. Compared to landfilling, anaerobic digestion and aerobic composting of organic waste results in less GHG emissions; CH_4 emissions from aerobic composting of food waste are estimated to be 0.042lbs./m^2.yr. In the literature, vermicomposting bins results in greater emissions than aerobic digestion and fewer compared to those of anaerobic digestion [18]. Mass of food waste diverted is directly related to the capacity of the composting system and the capability of the larvae to compost. Under the theoretical calculation of 25lbs are composted per day in 14 units, an annual total[12] of 427.5lbs. of CO_2e from CH_4 and 137.5lbs. of CO_2e from N_2O are generated by the system.

Conclusions

The results of this research show that the implementations of a food waste composting system using Black Soldier Fly Larvae faces considerable challenges. Although providing an innovative approach, higher intake capabilities of a variety of food waste, and various useful byproducts, the high maintenance costs associated with temperature conditioning of space are heavily impactful to the overall feasibility of the proposed system. GHG emissions from the proposed system are

[11] Corresponding to the usage of 1 type VII diesel vehicle [16].

[12] Corresponding to fugitive emissions characterized by [19].

significantly less than the current method by approximately 50% in CO_2e. Efforts in the future will include the completion of more trials to better understand the conditions and behavior of BSFL, and thus enabling the development of a controlled colony in on-campus facilities. Future work could address improving the efficiency of the system or alternatives that require less operational energy. Future research can include: the study of *Hermetia Illucens* for educational purposes in the field of life sciences and entomology, finding alternatives to utilize BSFL in the production of biofuel, and the potential use of BSFL as an alternative food sources for human consumption. Other promising opportunities involve the use of the byproducts for farming purposes, stimulating ties with local community and farms.

References

[1] United States Environmental Protection Agency (2013). "Reducing Food Waste for Businesses: Food Waste Basics". Wastes - Resource Conservation - Food Waste. United States Environmental Protection Agency - Official Website

[2] D. G. Wilson (1976). "A brief history of solid- waste management" International Journal of Environmental Studies. Vol. 9, Iss. 2. 123-129. DOI: 10.1080/00207237608737618

[3] P. A. Olivier (2009) "Utilizing lower life forms for the bioconversion of putrescent waste." Black Soldier Fly Blog - Official Website.

[4] B. Beck-Friisa, S. Smårsb, H. Jönssonb, H. Kirchmanna (2011). "SE—Structures and Environment: Gaseous Emissions of Carbon Dioxide, Ammonia and Nitrous Oxide from Organic Household Waste in a Compost Reactor under Different Temperature Regimes". Journal of Agricultural Engineering Research. Vol. 78, Iss.4, Pages 423–430

[5] ISWM-TINOS (2011). “LCA studies for composting and anaerobic digestion units”. Development and implementation of a demonstration system on Integrated Solid Waste Management for Tinos in line with the Waste Framework Directive. Municipality of Tinos, National Technical University of Athens, Università degli studi di Verona, Centre for Research and Technology Hellas / Institute for Solid Fuels Technology & Applications.

[6] T. Barry. (2004). “Evaluation of the economic, social, and biological feasibility of bioconverting food wastes with the black solider fly (Hermetia Illucens)” University of North Texas. UNT Digital Library.

[7] D. Craig Sheppard, G. L. Newton, S. A. Thompson, S, Savage. (1994) “A value added manure management system using the black soldier fly” Bioresource Technology. Volume 50, Issue 3, Pages 275–279

[8] C. Sheppard (1993) “House Fly and Lesser Fly Control Utilizing the Black Soldier Fly in Manure Management Systems for Caged Laying Hens”. Environmental Entomology, Volume 12, Number 5, pp. 1439-1442(4)

[9] S. St-Hillaire, K. Cranfill, M.A. McGuire, E.E. Mosley, J. K. Tomberlin, L. Newton, W. Sealy, C. Sheppard, S. Irving (2007) “Fish Offal Recycling by the Black Soldier Fly Produces a Foodstuff High in Omega-3 Fatty Acids”. Journal of World Aquaculture Society. Vol. 38, No. 2

[10] K. Bondari and D. C. Sheppard (1987) “Soldier fly, Hermetia illucens L., larvae as feed for channel catfish, Ictalurus punctatus (Rafinesque), and blue tilapia, Oreochromis aureus (Steindachner)” Aquaculture and Fisheries Management, Vol 18, 209-220

[11] Lalander, C., Diener, S., Magri, M., Zurbrügg, C., Lindström, A., Vinnerås, B. 2013. Faecal Sludge Management with the Larvae of the Black Soldier Fly (Hermetia illucens) - From a Hygiene Aspect. Science of the Total Environment (In Press).

[12] I. Banks (2012) “Black Soldier Fly Larvae – A Sustainable Protein Source?” London School of Hygiene and Tropical Medicine. Watershed - Official Website

[13] Walker, L., W. Charles, and R. Cord-Ruwisch (2009). “Comparison of static, in-vessel composting of MSW with thermophilic anaerobic digestion and combinations of the two processes”. Bioresource Technology. 100(16): p. 3799-3807.

[14] 4ft commercial ProtaPod™. (n.d.). ProtaCulture™ – Official Website.

[15] Biogrubs – Black Solider Fly Larvae. Compostmania™ – Official Website.

[16] EPA, Office of Transportation & Air Quality (2008, October). Average in-use emissions from heavy-duty trucks.

[17] Gray, D., Suto, P., Peck, C. (2008). “Anerobic Digesiton of Food Waste”. East Bay Municipal Utility District. No. EPA-R9-WST-06-004. U.S. Environmental Protection Agency Region 9. EPA – Official Website.

[18] Chan, Y., Chan, Y. C., Sinha, R. S., Wang, W. (2010). “Emission of greenhouse gases from home aerobic composting, anaerobic digestion and vermicomposting of household wastes in Brisbane (Australia)”. Waste Management & Research. 29(5): p. 540-548

[19] California Environmental Protection Agency (2011). “Method for estimating Greenhouse Gas Emissions Reductions from Compost from Commercial Organic Waste” Planning and Technical Support Division. California Air Resources Board.