The Future of Food Waste Disposal: Black Soldier Fly Larvae

Gabrielle M. Biordi

Miami University, Project *Dragonfly*, AIP

Issues in Cincinnati Conservation

Abstract

Waste disposal is of growing concern in our modern world. Improper disposal of waste in landfills leads to the release of greenhouse gasses and pollutants into the environment. The use of black soldier fly (*Hermetia illucens*) larvae to compost food waste can greatly reduce greenhouse gas emissions and create fertilizer and animal feed products. Household food waste from a family of three adults was diverted from the kitchen trash can into a compost system using black soldier fly larvae (BSFL) for a period of 19 weeks, and approximate greenhouse gas savings were calculated. During the experiment, the BSFL bin kept up with almost 100% of the household food waste (about 50 gallons), thus keeping five full kitchen waste basket bags worth of food out of landfills. The total greenhouse gas emissions were calculated at approximately 0.744 grams of methane and 1.6 grams of nitrous oxide, compared to 1,264 grams of methane and 46.872 grams of nitrous oxide for traditional composting.

Keywords: Compost, food waste, biowaste, waste processing, black soldier fly, Hermetia illucens

Black Soldier Fly Larvae: The Future of Biowaste Disposal

The proper disposal of waste is a growing ecological concern in today's society. In particular, food waste decomposing in landfills releases large amounts of greenhouse gasses that contribute to global warming. Landfills and wastewater constitute 18% of all human-driven methane emissions (Bogner et al., 2008). Composting food waste is a great way to produce organic growing medium or fertilizer that can be used in agriculture, while reducing greenhouse gas emissions and binding up to 54 kilograms of carbon per tonne of food waste in the soil, which is equivalent to up to 198 kilograms of CO_2 (Boldrin, Andersen, Møller, Christensen, & Favoino, 2009); this is the amount of CO_2 a car emits while driving 439 miles (U.S. Environmental Protection Agency, 2004). While composting in a large-scale facility can be useful for urban areas that produce large amounts of organic waste, composting in a backyard or small indoor system is also useful and feasible at the household level. In areas that do not already have a biowaste collection service, home composting keeps food waste out of landfills and uses it instead to amend garden soil, reducing personal greenhouse gas emissions, improving home gardens, and trapping carbon in the soil. Small-scale composting should also be more efficient and have a smaller carbon footprint because of the lack of fossil fuels needed to transport and process food waste. There are many common composting systems that are cheap and simple to set up for household use, including aerated piles, hot compost tumblers (rotating drums), and vermicomposting (using earthworms to digest organic waste) (Boldrin et al., 2009).

However, these traditional backyard composting methods are not typically conducive to the decomposition of meat, dairy, fat, and excessive grains. In order to ensure that no harmful pathogens survive in the finished compost, temperatures inside the compost pile or vessel must reach consistently high temperatures, which may not happen in poorly-managed backyard compost operations (Gold, Tomberlin, Diener, Zurbrügg, & Mathys, 2018). Luckily, there are methods that can safely break down these foods into usable compost, such as bokashi bins and well-aerated hot composting systems. One such method is using the larvae of black soldier flies (*Hermetia illucens*) to process food waste into soil conditioner while reducing the amount of harmful pathogens in the finished product.

Unlike composting worms (*Eisenia fetida* and others), black soldier fly larvae (BSFL) will feed on a much larger variety of food waste, including meat and dairy. They also reproduce relatively quickly, meaning the population can grow and process waste more quickly, often in under 30 days. Unlike other fly species, BSF are not considered pest species to humans, pets, or livestock, and actually reduce the presence of pest species around the composting area (Čičková, Newton, Lacy, & Kozánek, 2015; Hawkinson, 2005). In addition, fly pupae have been shown to be an excellent replacement for fish meal in animal feed; the pupae may be harvested in as few as 14 days and sold to offset the costs of composting or provide extra income. While the larvae grow, they reduce the wet weight of the biowaste by up to 80%; the remaining residue (or "frass," a.k.a. insect excreta) can be used as a fertilizer or soil conditioner, effectively recycling all organic waste put into the composting system (Lohri, Diener, Zabaleta, Mertenat, & Zurbrügg, 2017). In terms of greenhouse gas emissions, composting with BSFL releases much less greenhouse gas than traditional composting and landfills. BSFL composting only releases an average of 0.4 grams of methane per ton of organic waste, whereas traditional composting methods release anywhere from 30 to 6,800 grams of methane per ton of waste; that is a potential 99% decrease in methane emissions (Mertenat, Diener, & Zurbrügg, 2019).

Because my master plan is focused on invertebrates and their importance to a healthy planet, I looked further into BSFL composting for my household food waste. Most of our fruit and vegetable waste is already being composted in a compost tumbler, four small keyhole gardens, and a modest vermicomposting bin, but these are slow processes and cannot keep up with the rate at which we create food waste. Also, our meat, dairy, grease, grains, and food cooked with oils and condiments still goes in the trash can. I hope that by adding a BSFL bin to my composting efforts, I can keep that food waste out of landfills. I consider this project to be a proof-of-concept that I will eventually build upon to streamline and speed up the process. By thoroughly investigating the most efficient and ecologically sound composting methods, I hope to be able to share the benefits of composting with farmers and home gardeners in my community.

Methods

Baseline Measurements

I continued to use my existing composting methods for raw fruits and vegetables, and focused this experiment only on meat, dairy, grains, fats, and foods cooked with oil or condiments. The amount of food waste produced by my household (family of three adults) was measured for two weeks to determine a baseline for the study. Every day, food scraps were collected in a five-gallon bucket. Food scraps are defined as 1) uneaten food left on the plate at the end of a meal; 2) trimmings from meal preparation; and 3) leftovers that have gone bad and are no longer edible. No raw meat was disposed of during this project, but in the future, any raw meat will be cooked first to eliminate potential pathogens that could end up in the finished compost product.

At the end of the two-week period, our household filled only one five-gallon bucket with food scraps. The reason we did not fill more buckets was likely because a large portion of our diet consists of fresh produce, which is composted using the other methods described above.

Composting System Structure

I used a 32-gallon plastic bin with a locking lid as my composting vessel (*Fig. 1*). ⅗-inch holes were drilled in the lid for air circulation and to allow adult flies to come and go. Additional ⅗-inch holes were drilled along the bottom edges of the bin to allow the BSFL to exit when they are ready to pupate. Four more holes were drilled on the bottom to allow moisture to drain into the ground. The bin was placed behind the west side of our barn in a sunny location, as BSFs require sunlight to reproduce (Tomberlin & Sheppard, 2002).

Figure 1. BSFL composting bin.

The bin was filled about halfway with dry bedding (shredded cardboard, paper, and dry leaves) to absorb excess liquid, and then filled another fourth of the way with food scraps. The locking handles on the lid remained locked to keep out larger animals like mice, raccoons, and foxes.

An optimal food source is often enough to attract wild BSF to a bin (Bullock et al., 2013). I found that even before setting up the bin, the five-gallon bucket I had collected food in already had BSFL in it, and adult flies immediately swarmed the bin when placed outside. I monitored the bin in the following weeks to ensure that the flies continued to inhabit the bin. In the future, if no flies are found, or an overabundance of other species moves in, I will “inoculate” the bin with BSFL purchased from a reputable vendor.

Data Collection

From June 23 to October 30, I monitored *approximately* how long it took for the food waste to be broken down (i.e. whether it could keep up with the rate at which my household produced food waste), and whether the BSFL population seemed to be growing or waning. I kept a chart of how many five-gallon buckets I was able to process each week over the course of the project, and how many did not fit in the bin and therefore had to go into the trash. For each week I also marked whether the BSFL population appeared to be growing, waning, or holding steady, and the approximate state of decay/breakdown of the food already in the bin. Data was taken every Saturday and entered into the chart (Appendix).

Evaluation of Ecological Footprint

I used the figures reported by Mertenat et al. (2019) to calculate the potential greenhouse gas reduction from my composting process and finished product. Mertenat et al. (2019) found that BSFL composting released an average of 0.4 grams of methane and 8.6 grams of nitrous oxide per ton of wet waste, versus 30 to 6,800 grams of methane and 7.5 to 252 grams of nitrous oxide for traditional composting, depending on content and conditions. I converted how many gallons of food waste I collected into tons using an online measurement converter (Convsersion-Website.com, n.d.) in order to match the units used in Mertenat et al.'s research, then used their numbers to calculate the estimated greenhouse gas savings of my BSFL bin over the course of the experiment. I also calculated the volume of frass left after all food was processed at the end of the experiment by measuring the depth of the frass and multiplying it by the dimensions of the bin (25 x 15 inches), and converted it to gallons using an online measurement converter (Convsersion-Website.com, n.d.) to compare the wet weight of the food waste and the finished compost.

Other than assessing the potential greenhouse gas savings of this composting method, I also calculated the number of 10-gallon kitchen wastebasket bags saved from entering the landfill during the experiment based on the number of gallons of food the BSFL bin processed. I also calculated the distance a car could drive with the amount of greenhouse gas emissions prevented by using BSFL composting, using data from the U.S. Environmental Protection

Agency (2004) citing an average methane emission of .009 to .062 grams of methane per mile, depending on the car's built-in emission control technology.

Results

I found that the BSFL were able to completely process two weeks worth of waste (one five-gallon bucket) in only one week, meaning that they were easily able to keep up with the amount of food waste our household produced, and were even able to take some of the excess fruit and vegetable waste that did not fit in the other compost receptacles.


Black soldier fly larvae

Over the course of the experiment (roughly 19 weeks), we produced approximately 50 gallons of food waste (the equivalent of five full kitchen garbage bags), all of which was processed through the BSFL bin. With the addition of the BSFL bin, along with our existing composting methods, my family was able to keep almost 100% of our food waste out of landfills (we only put bones in the garbage). Those 50 gallons were transformed by the BSFL into a layer of frass at the bottom of the bin that was 6 inches deep, which is a total of 2,250 cubic inches (9.7 gallons) of frass; this means that the wet weight of our food waste was reduced by 80.6%.

Using the nitrous oxide and methane release estimates discussed, I calculated that my BSFL bin potentially released a maximum of approximately 0.744 grams of methane and 1.6 grams of nitrous oxide over the course of the experiment. This same amount of food waste could have released up to 1,264 grams of methane and 46.872 grams of nitrous oxide in a traditional composting setting; BSFL processing potentially reduced methane emissions by 99.9% and nitrous oxide emissions by 97.0%. The amount of methane I saved by using BSFL composting (1,263.26 grams) is equivalent to the amount released by a car after traveling 20,375 miles (with advanced emission control technology) or 140,333 miles (with poor emission control technology).

Discussion

In terms of the impact to my carbon footprint, this proof of concept experiment was a success. By processing my household's food waste with BSFL, I was able to reduce the amount of greenhouse gasses released by our kitchen scraps by 97 to 99.9% (0.744 grams versus 1,264 grams for methane, 1.6 grams versus 46.872 grams for nitrous oxide). The methane reduction alone would be enough for a car to travel from the east coast to the west coast of the United States 7.5 to 52 times, depending on the type of emission control technology in the car (worldatlas.com, 2016). It is worth mentioning that while carbon dioxide, another greenhouse gas, is released during composting, it is generally offset by the natural carbon cycle when the finished product is applied to soil, and so it is not counted in much of the literature (Mertenat et al., 2019), and therefore I did not calculate it for my project.

In addition to greenhouse gas savings, I also saved the equivalent of five full kitchen wastebasket bags (50 gallons) of food waste from entering the landfill, where they would not only take up space and add more plastic to the environment, but also release much more greenhouse gas as they decomposed anaerobically. Those 50 gallons were transformed into just 9.7 gallons of frass that can now be used as fertilizer for my garden.

These savings could have been greater had I started the experiment at the beginning of the summer. In terms of rate of reproduction and egg and larva survival, BSF do best at temperatures in the low-to-mid-80s (°F), but are still active into the mid-50s (°F) (Chia et al., 2018). Had I started the year with an active bin and fed it food waste during 50° to 90° weather (from, at most, mid-April to early November, according to the closest weather station [Smith Homestead - Saltair - KOHBETHE5, 2019]), I would have been able to save 7.5 wastebasket bags of food from the landfill; this, of course, assumes optimal weather conditions and relatively steady BSFL activity.

Due to personal circumstances, there was a period of about two weeks where I was not able to monitor the progress of my BSFL bin. Because of that, I missed the point at which the bin became too hot and forced all the flies and their larvae to leave. When I finally made it out to the barn to check on it, the only life in the bin was a handful of fruit fly larvae and some stray ants. I observed activity around the bin for several minutes, and saw that other fly species showed interest around the entry holes, but ultimately decided not to stay. Most of the food inside the bin was still untouched and only mildly broken down by mold. Luckily, about two weeks later, the BSFL showed up again en masse and began eating through the food waste with surprising speed, making up for lost time. Once the BSFL bin was running smoothly, we never hit a point at which we had too much food waste for them to process, and at the height of their larval activity (late September through October), it was not unusual for them to completely process a week's worth of food in just two days. True to previous research (Čičková, Newton, Lacy, & Kozánek, 2015; Hawkinson, 2005), once a steady BSFL population was established, they discouraged all other arthropods from taking residence in the bin; I never found another living thing in the bin, other than a spider that lived under the handle waiting for unsuspecting flies and larvae.

It is worth noting the limitations of this method for backyard composting. For those living in very cold or very hot climates, BSF season may be shorter or non-existent. Here in southern Ohio, we can reasonably assume about five cold-weather months where BSF composting is not possible. Another limiting factor for this method is the smell produced by the bin. My BSF bin emitted the most horrendous odor I have ever had the displeasure of experiencing. Especially in the hotter months, the stench of rotting food and larval frass could be detected several yards away from the bin itself. This would make this method very difficult for people with small yards or close neighbors who undoubtedly would not appreciate the olfactory intrusion. However, BSF composting is still a potential candidate for large-scale food waste processing (Gold et al., 2018). Facilities can be built away from residential areas and equipped with climate control measures to keep the BSF thriving year-round, and gasses released by the process could be filtered out of the facility and potentially sold for other uses. It would be well worth the additional research to determine whether the greenhouse gas savings and other carbon offsets of this method would outweigh the environmental costs of the facilities and infrastructure needed to streamline the process.

Reflection

I was shocked by how easy this composting method was compared to others I have tried. It is virtually maintenance-free, and can process large amounts of food waste in a short period of time. Unlike other methods, BSFL do not need a carbon source (and actually actively avoided it in my bin), so there is no complicated chemistry involved; all I needed to do was make sure the bin was in an area that received some sunlight, but would not get overheated, and nature took care of the rest. Several months worth of waste became a mere six inches of brown sludge at the bottom of the bin, which I can now add to my flower beds as fertilizer or add to my hot compost tumbler (to kill potential pathogens) and then use as fertilizer in the vegetable garden. I may actually replace some of my other less-successful composting methods with this one over the next year or two. In the future, I intend to try a mixed composting system with other arthropods such as skin beetles (*Dermestidae*), carrion beetles (*Silphidae*), and cockroaches (*Blattodea*).

Next year, I will continue to improve my BSFL bin. I will begin collecting yearly data on what time of year the BSFL first show up in the bin, how quickly they process food waste every month, and when BSFL activity ceases. With this information, I can better calculate my potential greenhouse gas savings and begin thinking of ways to optimize my food waste processing. I am also considering modifying the bin to allow BSF pupae to self-harvest, so I can gift or sell them to my neighbors as nutritious animal feed (I am told that chickens adore them). I may also ask my neighbors to bring me their food waste, since there were times that I struggled to keep the hungry larvae fed. Ultimately, I would like to be able to help my neighbors by reducing their food waste and providing food for their livestock. Perhaps, if I can outfit a shed or barn with heat, I could even continue the process through the winter months for continuous composting and pupae harvesting.

While the success of this project was not particularly surprising to me (from my research, I expected that it would be a very efficient waste treatment method), it was surprising to people I shared my results with. Because I am not a “math person,” I sat down with my father and asked for his help on some of my calculations, and as I explained to him what all the numbers meant, he kept trying to come up with reasons why BSFL processing could not possibly be as effective as it was. After sharing my research with him, he had no choice but to shake his head in confusion and admit that it seemed like an efficient method with many ecological as well as financial benefits. As someone who is still "on the fence" about climate change, seeing this response from him was encouraging to me; I feel like if I can argue my point to him, I may be able to convince others, as well.

Community Engagement Plan

Over the years, I have become increasingly fascinated by composting and the detrivorous flora and fauna at work in natural decomposition environments. I have long been testing different methods with the intention of eventually creating a user-friendly resource outlining the different methods available so that the average ecologically-minded person can find a method that works best for them. Now that I have three of the more common methods (hot compost tumbler, vermicomposting, and BSFL composting) fairly well figured out, I plan to create a series of short videos describing each composting process and how best to implement them at the household level. The videos will feature the environmental pros and cons of each method, the basic chemistry and biology of composting, step-by-step instructions for setting up your composting receptacle (and any relevant money-saving tips), basic maintenance, and how to harvest and use the finished product.

I can start working on the vermicomposting video at any time since the bin is kept indoors, but the compost tumbler and BSFL bin videos will have to wait until summer when the weather is more conducive to both composting and filming. As of right now, I plan to share the videos on my social media accounts for friends, family, neighbors, and other followers to view. After next semester, I will ideally have a sustainability blog set up, and will also post the videos there at that time.

My ultimate goal is to use social media—a platform that is often a source of scientific misinformation—to "bust myths" about biological topics and provide accurate scientific information in easily understandable terms (with relevant citations, of course). These videos will be just some of the content I create encouraging others to live more sustainably and respect our one and only Earth. If I can get even a handful of people to try to reduce their household food waste, that is potentially tons of food kept out of landfills, and tons of greenhouse gasses kept out of the atmosphere.

Conclusion

By processing my household's food waste through a BSFL composting bin, we effectively reduced our family's food waste nearly to zero. We kept 50 gallons of food waste out of the landfill and decreased the potential greenhouse gas released by 97% for nitrous oxide (~46.872 grams down to 1.6 grams) and 99.9% for methane (~1,264 grams down to 0.744 grams), compared to typical biowaste disposal methods. Our 50 gallons of food waste was reduced to a mere 9.7 gallons of frass (an 80.6% reduction), which can now be used as garden fertilizer.

Without lab conditions and instruments, I was not able to effectively measure the exact rate of decomposition or population of BSFL. In addition, due to the somewhat "wild" nature of an outdoor compost bin, as well as the addition of new food waste every few days, it was not possible to tell how long a specific piece of food waste had been in the bin or how long it took the flies to break down, say, a single chicken leg. In order to keep the system healthy and as natural as possible, I avoided disturbing the bin as much as possible, and therefore separation and counting of larvae was not feasible. Repeating this experiment under more controlled conditions to measure these variables could yield results that might be more useful for scaling up the BSFL composting process.

Diverting food waste away from landfills and into a more efficient waste management system such as BSFL composting would greatly reduce not only landfill real estate, but also greenhouse gas emissions, environmental pollutants, and waste in general, all while producing animal feed that could reduce or replace other, less environmentally friendly food sources (such as fish farms and largescale fishing operations), and fertilizer that could replace agricultural chemicals.

With climate change an ever-looming threat to the health of the planet, more efficient waste management techniques can make a significant difference in the amount of pollutants we put into our environment. While it may not be a viable method for all home gardeners, BSFL composting has proven to be highly efficient and warrants more research on making the process more reasonable for backyard use as well as large scale operations. Larger warehouse-like facilities could more easily control offensive odors and potentially capture methane and nitrous oxide for other uses by installing air filters in the composting area; however, the electricity requirement for the facility as well as the fuel used in transporting the food waste and finished products would need to be evaluated to make sure that they do not cancel out the ecological advantages of the BSFL composting process. In regards to fertilizer produced in the form of larval frass, more research is still needed to determine the types and amount of pathogens remaining in the finished product, as well as nutrient content compared to other forms of compost.

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Appendix

BSFL Bin Raw Data

Week	# 5gal buckets produced	# 5gal buckets added to bin	# 5gal buckets put in trash	Breakdown of food	BSFL population
06/23 - 06/29	0.50	0.50	0.00	N/A	Minimal, growing
06/30 - 07/06	0.50	0.50	0.00	N/A	N/A
07/07 - 07/13	0.50	0.00	0.00	None	All deceased due to heat
07/14 - 07/20	0.50	1.00	0.00	Minimal (mold)	All deceased due to heat
07/21 - 07/27	1.00	1.00	0.00	Minimal	Moderate
07/28 - 08/03	0.50	0.50	0.00	Moderate	Growing
08/04 - 08/10	0.50	0.50	0.00	Moderate	Growing
08/11 - 08/17	0.50	0.50	0.00	Moderate	Growing
08/18 - 08/24	0.50	0.50	0.00	Moderate	Steady, moderate
08/25 - 08/31	0.50	0.50	0.00	Most	Growing
09/01 - 09/07	0.25	0.25	0.00	Most	Growing
09/08 - 09/14	0.50	0.50	0.00	Most	Growing
09/15 - 09/21	1.00	1.00	0.00	All	Large, growing
09/22 - 09/28	0.50	0.50	0.00	All	Growing
09/29 - 10/05	0.50	0.50	0.00	All	Growing
10/06 - 10/12	0.50	0.50	0.00	All	Saturated
10/13 - 10/19	0.25	0.25	0.00	All	Saturated
10/20 - 10/26	0.50	0.50	0.00	All	Saturated
10/27 - 10/30	0.50	0.00	0.50[a]	All	All deceased due to freeze
Total	**10.00**	**9.50**	**0.50**		

Notes. N/A = weeks when I was unable to check the progress of the bin.

[a] = had to throw in trash after discovering the frozen BSFL