



Black Soldier Fly Larvae Composting at Bell's Brewery

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ABSTRACT

Bell's Brewery is currently seeking to divert 100% of their solid waste stream at their facilities. This study explores the use of black soldier fly larvae (BSFL) composting as a landfill diversion method for the screening solids produced by the brewing process. Three main experiments found that (1) the BSFL do eat the screening solids with a waste reduction ratio of 20:1, input to output; (2) temperatures inside the compost bin must be maintained so that the compost pile does not exceed 35.0°C (95.0°F) or fall below 18.3°C (65.0°F); and (3) an additional input of carbon to the system is highly recommended, but not required. A BSFL system is a feasible option for Bell's Brewery, however breeding the BSF's must first be solved before moving forward.

INTRODUCTION

Nationally, solid waste management is a reoccurring issue. In 2012, 251 million tons of municipal solid waste (MSW) was produced in the United States [9]. According to the United States Environmental Protection Agency, MSW (also known as trash or garbage) consists of everyday items that humans use and throw away at their homes, businesses, and schools. While landfilling is the least preferred method in the environmentally responsible solid waste management hierarchy [6], more than half of MSW is still landfilled. Of the total amount of MSW landfilled, a little over half consists of organic solid waste (OSW). OSW is any waste that is derived from plants or animals and is biodegradable. Craft breweries around the nation face the issue of large OSW streams produced in the brewing process.

The four main solid waste generation processes in craft breweries are brewing, packaging, food service, and special events [6]. Already a pioneer in sustainable brewery management practices, Bell's Brewery, Inc. of Kalamazoo, MI is currently seeking to divert 100% of the solid waste stream generated at their facilities. More specifically they are seeking to eliminate the organic solid waste that is a byproduct of the filtered wash water called 'screenings solids'.

The three main outputs of the brewing process are recoverable solids, beer, and soluble waste. Recoverable solids include spent grains, spent yeast, and trub; and are already being managed responsibly.¹ Soluble waste, on the other hand, is sent through an inclined filter to separate the solids and the liquids. All liquids are pumped to an anaerobic bioreactor and all solids are dropped into a dumpster. The solids, also known as "screenings", are then collected regularly and sent to a landfill. Landfilling creates hauling fees, greenhouse gas emissions, groundwater contamination, and more importantly prevents the valuable organic nutrients from being recycled into useful life processes.

Black Soldier Flies (BSF), or *Hermetia illucens*, are a wide-spread insect native to North America being studied for its ability to reduce organic waste volume and produce commercially valuable byproducts. When in larval form, they have voracious appetites for decaying organic matter with the capacity to eat three times their body weight per day under optimal conditions.

This project explores the feasibility of a Black Soldier Fly Larvae (BSFL) composting system to reduce landfill volume at Bell's Brewery. We propose that BSFL composting can be a sustainable alternative to the current practices of landfilling the screenings solids produced in the brewing process.

¹ Bell's Brewery sends all recoverable solids to local farmers for use as a highly digestible animal feed.

METHODOLOGY

To test our proposal, we started by building six compost bins and a breeding structure. Every two weeks a different experiment was conducted. The three main experiments piloted were: waste reduction ratio, temperature needs of larvae, and carbon: nitrogen ratio. Bell's regularly provided a sealed 55 gallon drum filled with screenings to feed to each compost bin. Larvae inside the compost bins fed until reaching full maturity then developed into pupae. Pupae self-harvest, or remove themselves from the compost pile, migrate up a 35° ramp² and fall into a 5 gallon collection bucket. Pupae were then moved from the collection bucket to the *Honeymoon Hotel*, or breeding structure, where they emerged into adult flies and mated. To close the loop within the system, the eggs oviposited by adult females on strips of cardboard were carried to the compost bins. Eggs hatched inside the compost bins, where newly emerged larvae had access to plenty of food and continued the BSF life cycle.

a) BSFL Lifecycle

The life cycle of a BSF can be four weeks to nine months depending on living conditions. They are incredibly tolerant insects that can handle temperatures from 4.0° to 43.0°C (49.2° to 109.4°F). At the optimal temperature of 29.4°C (85.0°F) and relative humidity of 70% a population of the larvae that are approximately the same age will feed for about two weeks. However, if the temperature is not ideal or there is not enough food available, the larvae can take months to mature. BSFL can eat three times their body weight in a day leaving us with a 90% volume reduction, of all organic waste near them. Upon reaching maturity, the larvae's mouth is replaced with an appendage and their complexion darkens in color; they are now called pre-pupae. Instinctively pre-pupae self-harvest, or remove themselves from the compost pile, to migrate to a dry, dark spot to pupate. A collection bucket sprinkled with saw dust was used to act as a dry, dark place. Pupae were collected and moved from the compost bins to the breeding structure. The pre-pupae become pupae. For 2-4 weeks the pupae were dormant while they developed into adult flies. After that time period, adult flies emerged from the pupae shell and lived for 1-5 days to reproduce. Adult flies do not have mouths; therefore they are not a disease vector for human pathogens. Adult female BSF's will oviposit one cluster of eggs with up to 900 eggs per cluster [12].

b) BSFL Compost Bins

In order to carry out a pilot study; we started by building six compost bins: three Protapods™ [12] and three do it yourself (DIY) bins. Two of the DIY bins were not used during this study. In the below sections the bins are described more thoroughly. All screenings from Bell's were fed into the compost bins. The screenings consisted of spent grains, hop residue, and trace amounts of food grade caustic cleaning solution used in the lauter tun. We chose to use Protapods™ and DIY bins to compare how they operate, as well as learn how to design and construct a DIY bin that could be scaled up to meet the

² The requirement for a pupae migration ramp is a less than or equal to 40° angle.

volume needed by Bell's. For larval feeding, the optimal conditions within a compost bin are 29.4°+- 10.0° C (85.0° +- 10°F) with 70% relative humidity.

i) Protapods™³

- (1) A Protapod™, designed by Prota Culture LLC, is the largest commercially designed BSFL compost bin on the market. The Protapod™ is a polyethylene unit that has a 44 in top diameter, 34 in bottom diameter and an overall height of 26.4 in. Based on a half-full unit, the digestion rate is 21 lbs of organic waste a day [12].

To capture leachate drainage and make the bin more accessible we built a 55.8 cm x 55.8 cm x 48.2 cm (22.0 in x 22.0 in x 19.0 in) square stand from reclaimed 2.0 in x 4.0 in lumber. A 5 gal bucket sat under the stand to collect leachate. For the cooler, winter months each Protapod™ was wrapped with a 53.3 cm x 152.4 cm (21.0 in x 5.0 ft) 120V AC Redi-Heat heat mat and faced fiberglass Batt and roll insulation. A 2.5 cm (1 in) extruded polystyrene foam board insulated lid with 8 mm (0.375 in) wood top was built to aid in insulation.

ii) DIY Bins⁴

- (1) A DIY, or do-it-yourself, bin is an in-house design utilizing locally sourced materials. The DIY bin was designed with the same speculations (e.g. surface area, ramp) of the Protapod™. However, because the Protapod™ design does not allow for more than 21 lbs of waste input a day, we designed for the DIY to be scaled up. Major considerations included in the design were drainage, insulation, ventilation, and larval crawl off. A list of materials per bin can be found in Figure 1.

³ Please refer to Appendix III, Section 1 for a visual representation.

⁴ Please refer to Appendix III, Section 2 for a detailed sketch as well as photos.

Materials per Bin

- (5) 2 in x 4 in x 96 in Reclaimed lumber
- (1) Plytanium 23/32 x 4 in x 8 in Pine Sheathing Plywood
- (1) 10 ft x 36 ft 9 oz Black Vinyl Tarp – Reused Billboard
- (2) Extruded Polystyrene Foam Board Insulation 1 in x 4 ft x 8 ft
- (1) 1 lb #8 x 3 in Bugle-Head Phillips Drywall Screws
- (3) 21 in x 26.5 in Coconut fiber coir mat
- (1) 3 ft L, 4-1/2 in W Genova Raingo White Vinyl Gutter
- (2) Raingo White Gutter Bracket
- (1) 4-1/2 in Raingo White Vinyl Outside End Cap
- (2) 10 lb bag of gravel
- (2) Economy 5 gal bucket
- (1) Mosquito Net Bed Canopy
- (3) BSFL starter colony

Figure 1: Full list of materials used to build a DIY BSFL compost bin.

c) Experiments

Each compost bin was monitored and documented daily with an Ambient Weather WS-10 Indoor/Outdoor Wireless Thermo-Hygrometer and BSFL compost bin data sheet.⁵ The sensors displayed current temperature, maximum temperature, minimum temperature, current relative humidity, maximum relative humidity, and minimum relative humidity per sensor. After documenting in the BSFL compost bin data sheet, the data logger was reset to prepare it for the next day.

i) Experiment #1: Waste reduction ratio

The waste reduction ratio is a comparison of input to output in a compost system; in our case, screenings waste to grub castings. After all larvae reached full maturity, transitioned into pupation, and the bins were notably inactive, we harvested the bins. Harvesting takes place approximately 6 weeks after the larval population begins. A harvest consisted of emptying a compost bin onto a table and sifting through the castings using our hands to separate the casting solids from any remaining pupae. We totaled the amount of input added to each bin and weighed the total amount of output per bin to calculate a waste reduction ratio. The first harvest (January 16, 2015) consisted of a wet screenings input to wet castings output ratio while the second harvest (April 10, 2015) was a wet to dry

⁵ See Appendix IV for a screen shot of the *BSFL Compost Bin Data Sheet*.

ratio. The variation in moisture was due to extended time left out and varying outside environmental conditions.

ii) Experiment #2: Temperature needs of larvae

Inside each bin hung a white digital sensor that recorded the air temperature and relative humidity of that bin. Each day the current, maximum, minimum temperature and current, maximum, minimum relative humidity were recorded from the sensors while compost pile temp was recorded with a compost thermometer at a depth of six inches. The compost pile thermometer was left in place until the temperature stabilized for 30 seconds.

iii) Experiment #3: Carbon: Nitrogen ratio

The third experiment was focused on the carbon to nitrogen ratio within the BSFL compost bins. In composting, the carbon to nitrogen ratio is an important factor because if it is off balance, the bioconversion gets set off balance. When there is too much carbon, decomposition slows down. When there is too much nitrogen, the compost pile becomes anaerobic and foul-smelling. BSFL prefer nitrogen rich material over carbon rich material. Since the screening solids were mostly likely nitrogen rich as suggested by the presence of an ammonia smell, we proceeded to add carbon in attempt to balance the ratio.

Two pounds of dried oak leaves were added to Protapod™ #2 on March 3. The oak leaves were collected November of 2014 and stored in dry brown paper bags inside the hoop house. The temperature conditions for storage correspond to Kalamazoo, Michigan November 2014 temperature ranges of -10.5°C to 16.1°C (13.0°F to 61.0° F). Protapod™ #2 was checked each day for foul smells and larval feeding on the carbon. Any changes were noted in the monthly *BSFL Compost Bin Data Sheets*.

d) Breeding Structure⁶

The BSF breeding structure, also known as, ‘*The Honeymoon Hotel*’ is a specific structure for adult BSFs to reproduce. Optimal breeding conditions are 82.0° F with 60% +- 30% relative humidity. We looked at two different designs for BSF breeding: a horizontal design and a vertical design.

i) Horizontal design

Before we began drawing up a design for a breeding structure, an already existing experimental structure was loaned to us by a colleague. The structure was a 4 ft W x 2 ft H x 2 ft D rectangular container with nylon window screen as walls. Inside the structure was a heat mat, a plastic Tupperware holding food waste, a house plant, a 60 Watt (W) light, and small cup of water were used in efforts to promote breeding.

⁶ Please refer to Appendix III, Section 3 for a visual representation.

ii) Vertical design

The second design was vertically integrated considering insulation, ventilation, proper flying space, and lighting needs. The light was timed to go on at 7AM and turn off at 9PM. Many changes occurred while setting up to test the balance between lighting, temperature, and relative humidity. See Figure 2 for a list of materials used to build the vertical design.

We began testing the structure on February 1 with a Sylvania halogen double-life 60 W bulb. Alone, the Sylvania 60W halogen bulb was not enough to promote breeding, so we added a 15 W compact fluorescent lamp (CFL). Finally we replaced the Sylvania 60 W halogen bulb with a Zoo Med FS-C10 Reptisun 10.0 UVB. The Zoo Med FS-C10 Reptisun 10.0 UVB provided UV light and heat while the Bright Effects 15W CFL provided additional lumens and full-spectrum light. Effects of these changes can be found in the results section.

Honeymoon Hotel Materials List

- (1) Recycled 58x23 cubic in refrigerator
- (1) Light fixture
- (1) Sylvania 60 W halogen bulb
- (1) Bright Effects BE15T3/D
- (1) Zoo Med FS-C10 Reptisun 10.0 UVB
- (3) 2 ½ in D, #12 mesh screen(for ventilation holes)
- (1) Mosquito Net Bed Canopy
- Interior:
 - (1) House plant
 - (1) Pupae bin
 - (1) Water & gravel bin
 - Cardboard rolls
 - (1) Interior screen
 - (2) ½ round PVC pipe
 - (3) Thermometer
 - (1) Ambient Weather WS-10 Indoor/Outdoor Wireless Thermo-Hygrometer

Figure 2: Full list of materials used to construct a breeding structure.

RESULTS

BSFL Compost Bins:

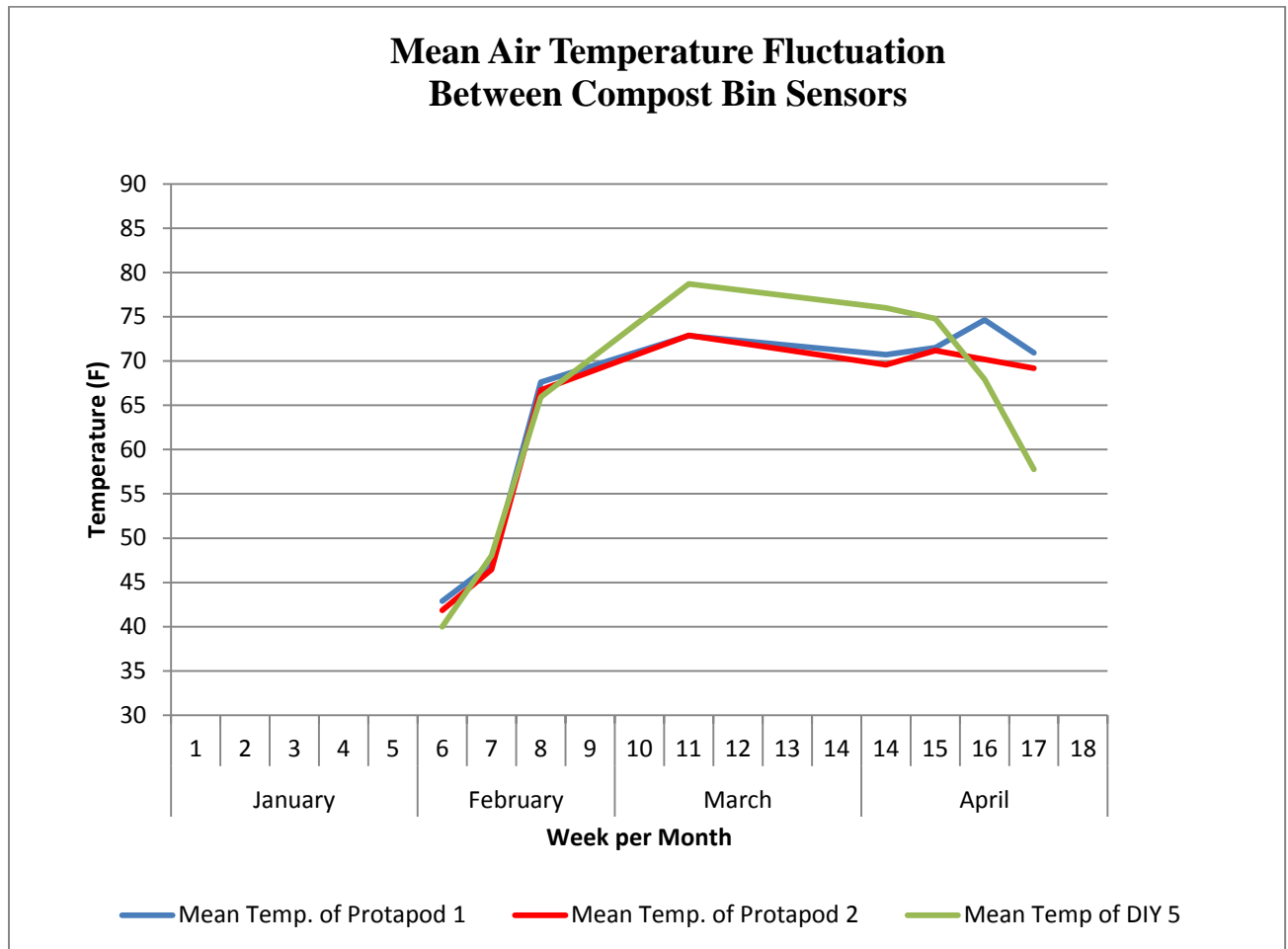


Figure 3: Mean air temperature fluctuation between compost bins per week per month.

There was a variation of 14.2° to 25.9° C (57.5° to 78.7° F) between the mean air temperatures inside the bins. While all three bins (Protapod™ #1, Protapod™ #2, and DIY #5) stayed relatively consistent, we found that DIY #5 had about a 7.0 °F higher mean temperature from week 10 to week 15.

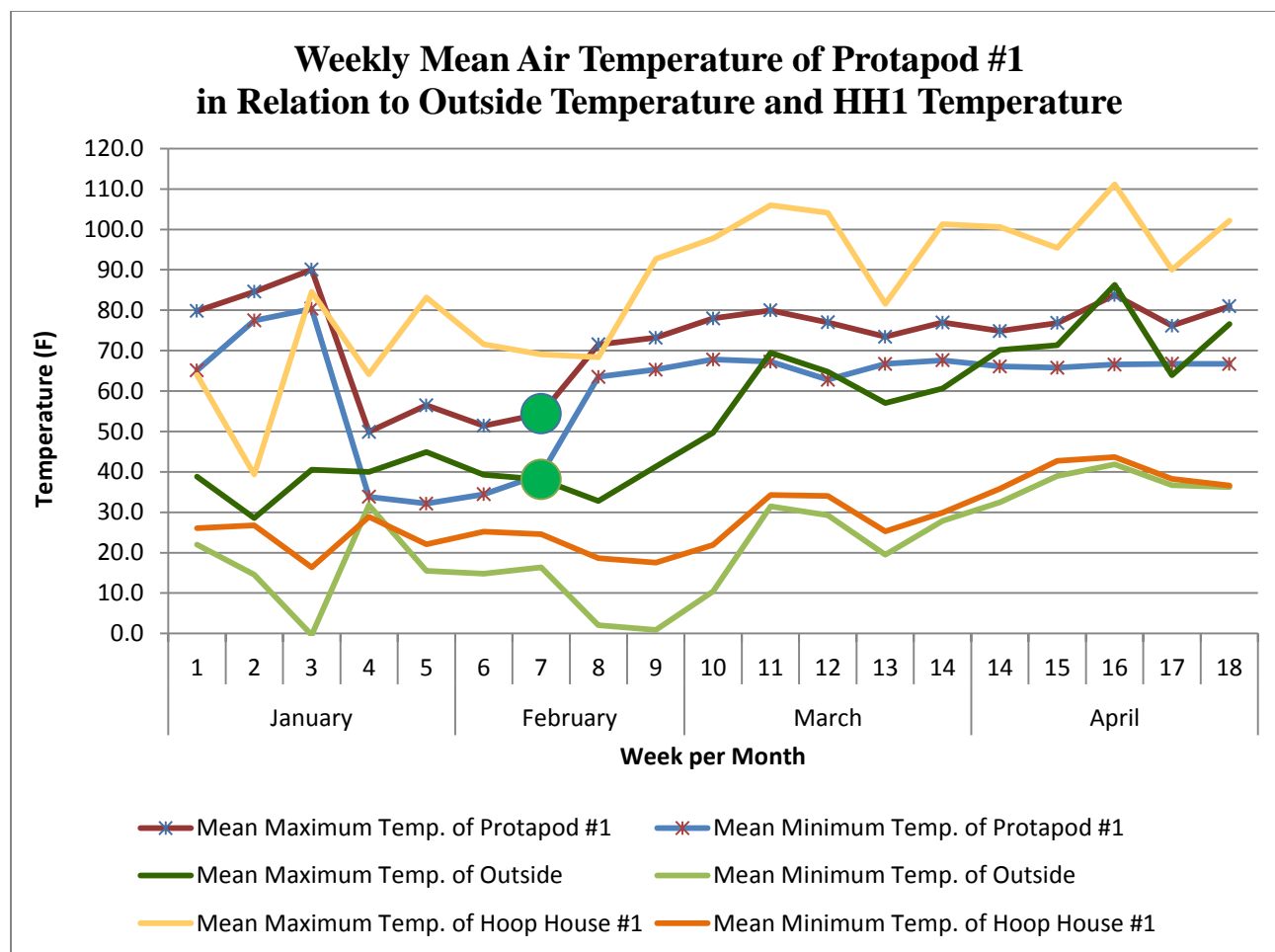


Figure 4: Weekly mean air temperature of Protapod™ #1 in comparison to the outside and hoop house #1 temperatures per week per month.

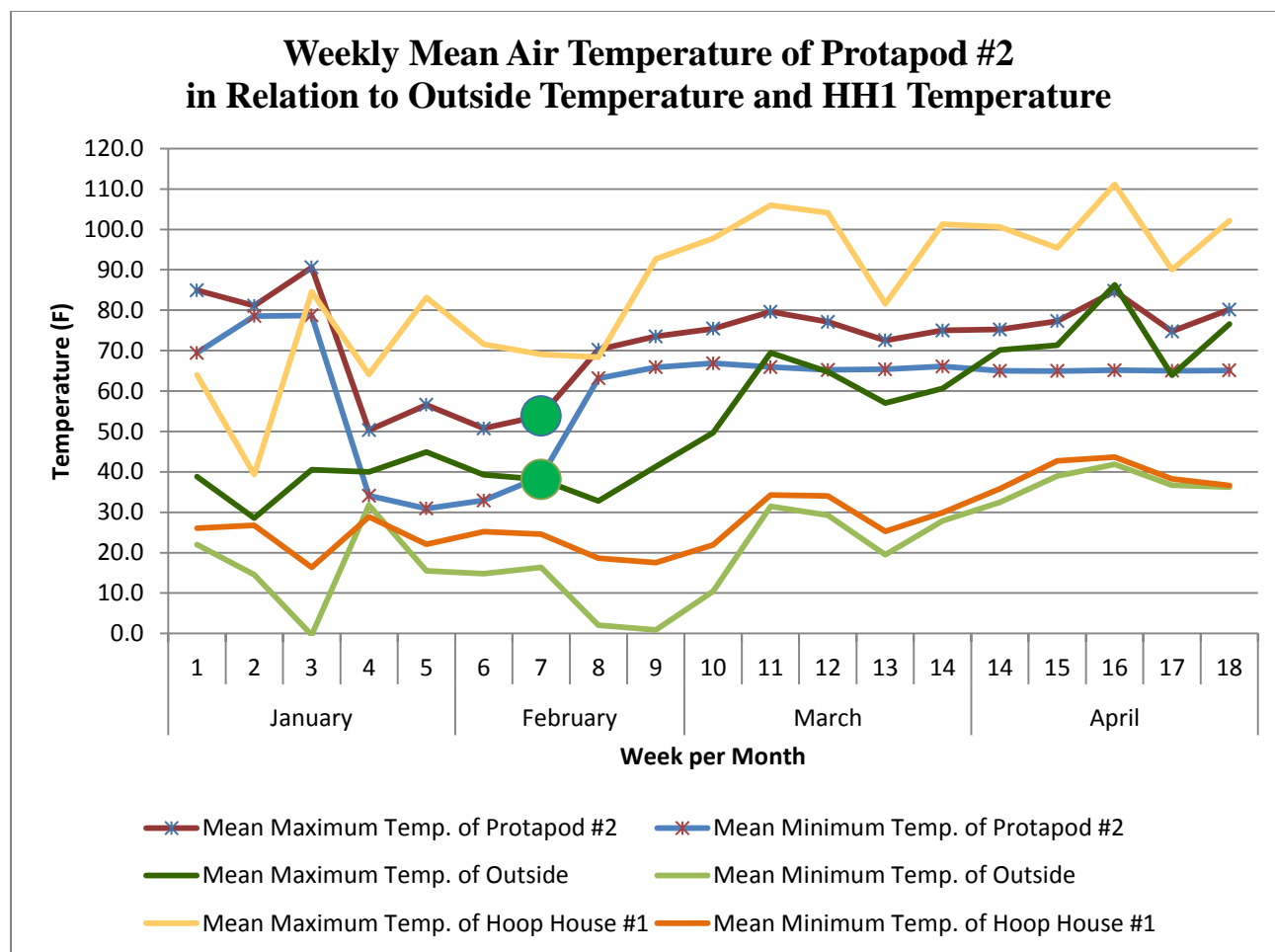


Figure 5: Weekly mean air temperature of Protapod™ #2 in comparison to the outside and hoop house #1 temperatures per week per month.

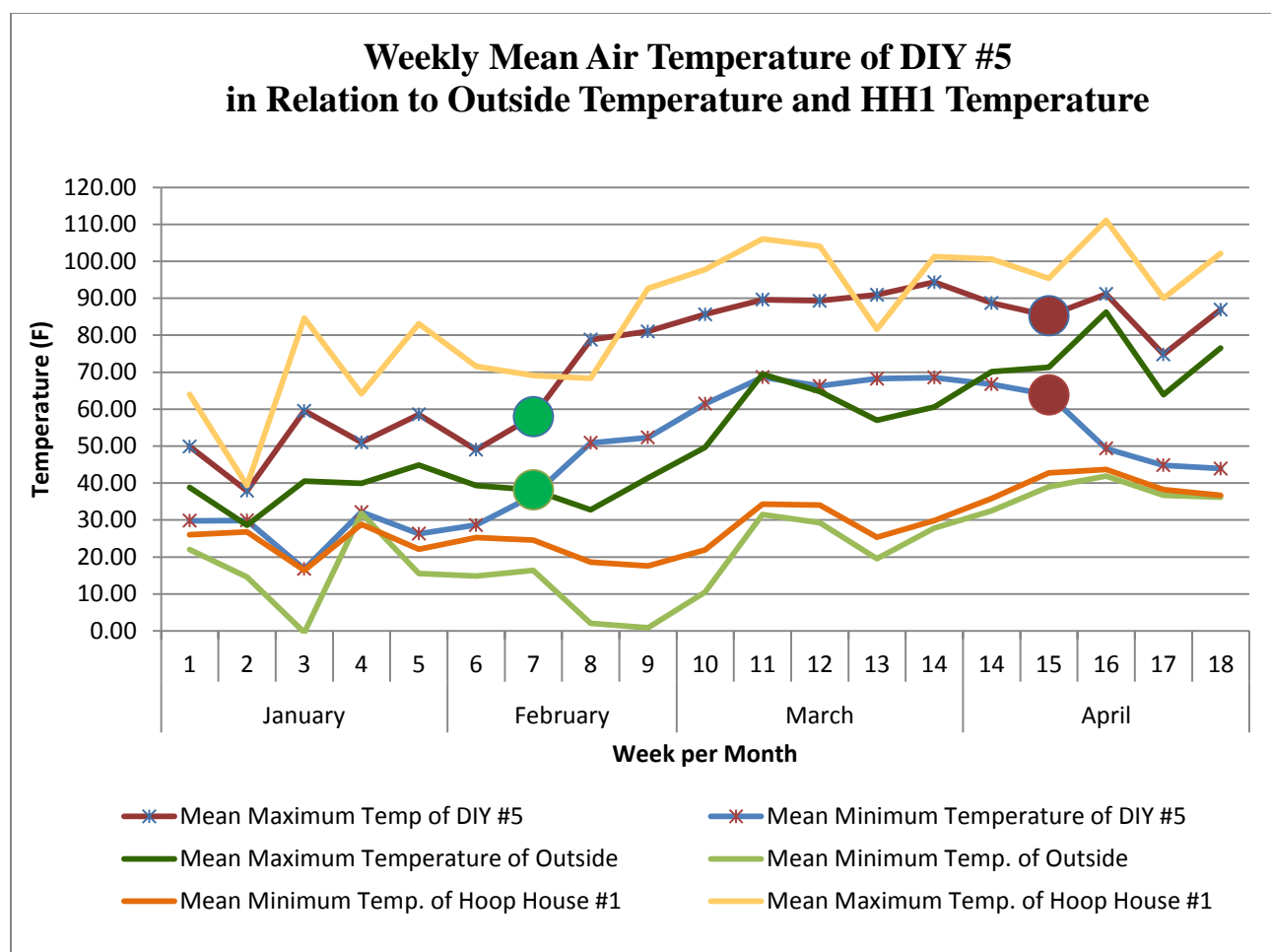


Figure 6: Weekly mean air temperature of DIY #5 in comparison to the outside and hoop house #1 temperatures per week per month.

There was a range of -20.6° to 43.9° C (-5° to 111.1° F) between the mean maximum and mean minimum temperatures of hoop house 1, and the outside; yet the bins stayed relatively close in range. Figure 4, Figure 5 and Figure 6 display each compost bin in comparison to the hoop house and outside temperature. The BSFL population began on February 12th in week 7 and was harvested on April 10th in week 15.

The green dots in Figure 4, Figure 5 and Figure 6 indicate when the new larval population arrived and was introduced to the compost bins. The green dots also indicate when we began inputting screenings waste. The red dots in Figure 4, Figure 5 and Figure 6 indicate when the compost bin was harvested. We did not harvest Protapod™ #1 and Protapod™ #2 during the second harvest to allow them to pupate inside the bins in an effort to encourage outdoor breeding.

Byproduct Generation/ Outputs

Pupae

We are unable to say the exact amount of pupae that were harvested due to premature crawl off and in-vessel pupation of larvae. We found that the pupae prematurely remove themselves from the compost pile when temperature is greater than 35.0° C (95.0° F) inside the compost bin. Premature crawl off was most apparent within DIY #5 during week 11 of the pilot study. This was addressed by adjusting the temperature from 23.9° C (75.0° F) to 18.3° C (65.0° F) in the DIY Bin. We also found that putting two cups of saw dust inside the pupae collection bucket helps to contain the pupae from crawling out. Without sawdust the pupae will suction themselves to the sides of the bucket using the surface tension of water and crawl out of the bucket.

Leachate

Between February 13 and April 10, we collected a total 34.21 L (9 gal) of leachate; 19.48 L (5.1 gal) of leachate from Protapod™ #1, 14.53 L (3.8 gal) from Protapod™ #2, and 200 mL from DIY #5. There was a linear relationship of increased leachate production with an increased input of waste. Additionally, leachate attracts and encourages adult female BSF's to lay eggs. [12]

Castings

At the first harvest (trial harvest) on January 16, 2015, we harvested Protapod™ #1, Protapod™ #2, and Protapod™ #3. Protapod™ #1 had a total weight of 23.6 kg (52 lbs), Protapod™ #2 had a total weight of 29 kg (64 lbs) and Protapod™ #3 had a total of 26.3 kg (58 lbs) of wet castings. At the second harvest on April 10, 2015, only DIY #5 was harvested. DIY #5 harvested a total of 1.4 kg (3.1 lbs) dry castings. The castings were dry due to increased ventilation of environmental conditions and did not make a difference in the reduction ratio.

Experiments

Experiment #1: Waste Reduction Ratio

DIY #5 had a total input of 28.6 kg (63 lbs) screenings between February 13 and April 10. As stated above, the total end harvest was 1.4 kg (3.1 lbs) of castings. The waste reduction ratio resulted in a 20.3:1, waste input to castings output ratio.

The moisture content of the castings did not play a significant role in the waste reduction ratio. However we noticed more pupae inside the wet output.

Experiment #2: Temperature needs of Larvae

There was a clear variation between the set dial temperature, the digital sensor temperature (air temperature inside compost bin) and the compost pile temperature inside the bin. We found that the set dial temperature, on average, was 13.3° C (8.0° F) lower than the sensor temperature. The sensor temperature read -12.8° +/- 1.0° C (9.0° +/- 1.0° F) less than the compost pile in Protapod™ #1 and Protapod™ #2. The sensor temperature in DIY #5 read about -8.3 +/- 3.0° C (17.0° +/- 3° F) less than the active compost pile. When less active, the compost pile temperature was much closer in range to the sensor temperature, but still at least -15.0° C (5.0°F) warmer.

BSFL can handle a large range of conditions. We found that the larvae can survive conditions near freezing point; however, we don't recommend allowing a system to fall below 12.8° C (55.0° F).

Experiment #3: Carbon: Nitrogen Ratio

As a result of the carbon to nitrogen ratio inside the compost bins, we found that the larvae prefer nitrogen-rich organic material over carbon-rich organic material. By observing the level of decomposition and location within the bin the leaves went untouched for 58 days of the experiment beginning March 3 and ending April 30. A carbon addition of 2 lbs to 63 lbs screenings was observed to decrease the ammonia smells to an unnoticeable level that was much healthier for the operator.

Breeding Structure

Adult flies reproduced more frequently at temperatures between 15.6° and 35.0° C (60.0° and 95.0° F) with relative humidity levels between 45% and 70%. The repurposed fridge held consistent temperatures measured at different lengths from the light and relative humidity when moisture was added regularly. See Figure 7.

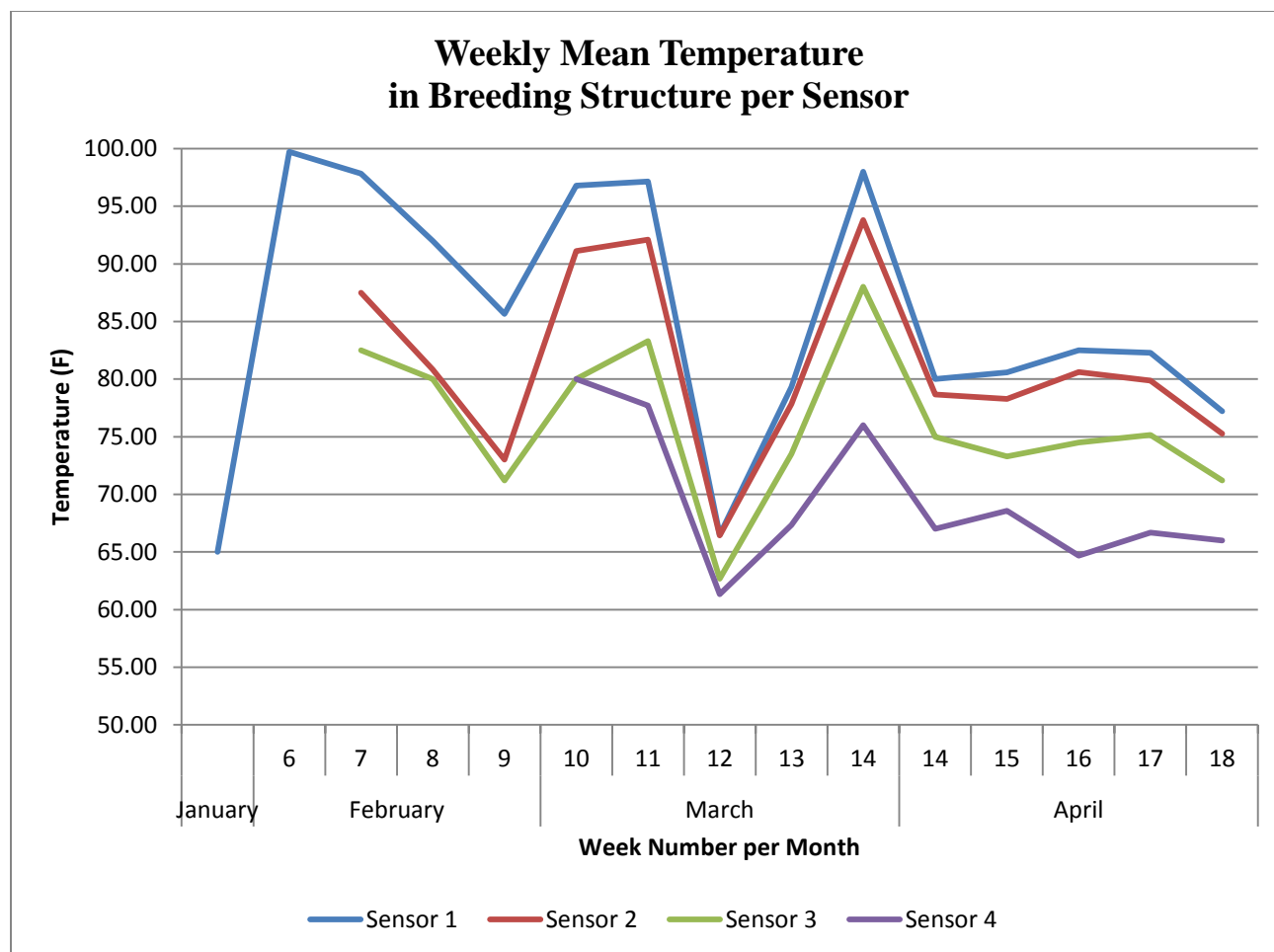


Figure 7: Weekly mean temperature inside the breeding structure.

Lighting is a crucial parameter when attempting to create an artificial environment ideal for breeding. Starting with a Sylvania 60W halogen bulb, there was no observed breeding. A 15 W CFL was added. The combination acted as a thermo-regulator and artificial daylight, yet still no oviposition was experienced. Finally we replaced the 60W halogen bulb with a 26 W UV reptile CFL. The final combination of a 15 W CFL and 26 W UVB provided a consistent temperature of $28.9^{\circ} \pm 16.1^{\circ} \text{ C}$ ($84^{\circ} \pm 3^{\circ} \text{ F}$) and simulated daylight. Breeding flies were observed and eggs were found in the corrugated fiberboard, however not on a consistent basis.

The first discovered eggs were on April 3. Though we did have a few adult BSF's lay a cluster of eggs, we were unsuccessful in bringing them through maturity into hatching.

DISCUSSION

BSFL Compost Bins

BSFL can digest and efficiently consume the solid waste screenings produced at Bell's Brewery. Based on the results, we can confidently say the commercial Protapod™ design works better than our DIY design. Though they had equal waste reduction ratios as well as similar interior temperatures, the drainage within the DIY bin was unsuccessful. It is believed that this was due to the placement of the heat mat inside the DIY design. A specially designed compost bin will be needed to a scale that matches the estimated 396 tons (produced in 2015) of screening solids at Bell's Brewery.

It is estimated that Bell's produces 2 cubic yards of screening solids a day. There are approximately 2,500- 2,550 larvae per square foot, or 3 lbs of organic waste. To manage the estimated production of 2 cubic yards of waste per day Bell's would need approximately 1.4 million grubs, weighing roughly 480 lbs.

At the optimal temperature range of 26.7° to 35.0° C (80.0° to 95.0° F), and with the appropriate population of larvae per volume, larvae will 'compost', or digest, the waste within 1 day. Due to the small particle size of the screenings the larvae are able to consume evenly over a large area; thus speeding up the bioconversion rate. If the temperature is not ideal or there is not enough food available, decreased larval feed rates, and/or premature crawl off may occur.

Experiments

1. Experiment #1: Waste Reduction Ratio

We can conclude from the first experiment that the 20:1 input to output ratio was verified. For every 2 cubic yds, or 1,700 lbs of screenings input, Bell's will collect an approximate output of 2.7 cubic feet, or 84 lbs of castings.

If Bell's were to continue to landfill the castings after the BSFL screenings volume reduction, it is estimated that they will have an annualized savings of \$24,624 in 2015. With an estimated annual 20% increase in screening solids production, you can observe the linear relationship in Figure 8.

Year	Weight (tons)	Cost	Weight after BSFL (tons)	Cost after BSFL	Annualized Savings with BSFL
2015	396	\$25,920	20	\$1,296	\$24,624
2016	475	\$31,140	24	\$1,557	\$29,583
2017	570	\$37,324	29	\$1,866	\$35,458
2018	684	\$44,789	34	\$2,239	\$42,550
2019	821	\$53,747	41	\$2,687	\$51,060

Figure 8: Operational cost savings with BSFL composting with a 20% increase in production each year.

2. Experiment #2: Temperature Needs of Larvae

In the results, we observed that the compost pile temp is $-9.4^{\circ} \pm 5.0^{\circ} \text{ C}$ ($15.0^{\circ} \pm 5.0^{\circ} \text{ F}$) warmer than the surrounding air temperature inside the bin. BSFL can survive in the range of 4.4° to 43.3° C (40° to 110° F). However, if the compost pile temperature exceeds 35.0° C (95.0° F), premature crawl off will be experienced with a corresponding reduction in feeding efficiency. If the compost pile temperature falls below 18.3° C (65.0° F) larval feed rates will decline. To ensure the temperature does not exceed this range, we recommend Bell's regulates the compost pile with a thermostat. The sensor should be positioned inside the compost pile. Air temperature is a secondary consideration to regulate, because if air temperature falls too low the grubs will pupae inside the bin.

An indoor compost system during the cooler, winter months will require additional heating to maintain the system from falling below 18.3° C (65.0° F). The additional heating will be at a minimum due to the heat produced by the larvae. Additionally, an indoor compost system during the warmer, summer months will require ventilation and possibly cooling so that the compost pile does not exceed 35.0° C (95.0° F).

3. Experiment #3: Carbon: Nitrogen Ratio

We can conclude from the third experiment that carbon will eliminate the smell of ammonia; though, it is not necessary for the functioning of the system. Excess

ammonia gases pose a threat to the operator's health if inhaled. Typically the bins stay free of pungent smells if not overfed. Since the waste Bell's is dealing with is nitrogen rich, adding a minimal amount of carbon to the system is recommended to reduce odors. Carbon sources can come in many forms but sourcing a locally available bulking material is recommended to reduce transportation costs, expense in handling a bulky material, and carbon footprint. Common carbon sources include leaves, shredded paper, shredded cardboard, wood chips, hay, and sawdust. We suggest further research to quantify the precise carbon to nitrogen ratio needed within a BSFL compost bin as no published data could be found.

BSFL System Output

At 2 cubic yards of screenings input per day and with the capacity of 480 lbs larvae, Bell's system would produce 62 gal of leachate and 84 lbs of castings per day. Pupa output will be dependent on the population size of the larvae.

Value of the byproducts

Companies around the world specializing in BSFL make a large profit through sale of BSFL products. Below I have discussed the three most significant products and their value.

(a) Pupae

During the pupation stage, the insect is dormant and at its highest nutrient content; making it a significant product of system. While approximately 10% of the pupae harvested can be moved to a confined structure for oviposition, the remaining 90% can be used as a high protein-high fat animal feed. Birds, reptiles, fish, livestock and humans all make for excellent consumers. When pupae are in this dormant life stage, they are at their highest nutrient content; roughly 42.1% crude protein and 34.8% lipid respectively [3]. Pupae are marketable to anyone with livestock, fish, or reptiles.

(b) Leachate

Leachate from the compost bins can be used to create a liquid fertilizer and/or compost tea. The leachate can be sprayed directly on plants, however it is recommended to dilute both leachate and compost tea 10:1 with water. The value and effectiveness can be increased by creating a compost tea. To create a compost tea, aerate the leachate, add molasses, any desired micro nutrients, and mix with water at a 10:1 water to compost tea ratio. The leachate also aids in luring adult female flies to oviposit eggs in desired areas [12]. It is recommended to keep the leachate aerobic to avoid any anaerobic bacteria from cultivating.

(c) Castings

A nutrient analysis was not performed on the BSFL castings. BSFL convert organic waste into a living protein. They are not great soil builders because their digestive track is short, limiting their ability to produce high quality compost. This nutrient content is inferior to many other types of compost (e.g.

Vermicompost); however they can still be utilized as a soil builder adding some nutrients and more importantly organic material.

Annualized savings using BSFL vs. current practices

Currently, Bell's Brewery pays \$40 per ton for solids to be sent to the landfill. Additionally, this cost comes with a \$280 hauling fee. In 2015, Bell's averaged three trips per month at 10 to 12 tons per trip. That brings us to an average annual operating cost of \$25,920 for 2015. If BSFL composting were to be implemented at Bell's, the reoccurring costs of hauling and landfilling could be eliminated or significantly reduced.

Landfilling costs are linear to growth in production. See Figure 9 to observe the costs associated with a conservative estimated annual growth of 20% in screening solids production.

Year	Weight (tons)	Cost
2015	396	\$25,920
2016	475	\$31,140
2017	570	\$37,324
2018	684	\$44,789
2019	821	\$53,747

Figure 9: Landfill cost associated with increased screenings production each year

LIMITATIONS OF ANALYSIS AND PROPOSED FUTURE WORK

In view of the future, it is recommended that this project moves into a second phase focusing on breeding BSFs. It becomes impractical to perpetually purchase a new starter colony of larvae each time they reach their full lifecycle. Breeding BSFs is absolutely necessary and we must solve this problem before moving forward. Additionally, we do not recommend separating the breeding structure from the compost bins. This is due to adult female BSFs avoiding anaerobic places when laying eggs. With a system that unifies composting and breeding, anaerobic waste

will not be an issue because as larvae feed, they keep the bin an aerobic atmosphere thus attracting adult females.

For optimal data collection regarding environmental conditions such as temperature and relative humidity, it is advised that an automated data collection system be in place. An automated system allows for more consistent, frequent data points, detailed statistics, and reduced labor costs. Additionally a quantum meter would be used to measure light intensity for breeding purposes.

Proposed future work entails finding the exact C: N ratio, redesigning the DIY bin, and utilizing more collaboration⁷. A nutrient analysis would be conducted to find the nutrient content and market value of each system byproduct. Energy efficient practices would be tried in maintaining an all-season system. Weight increase of the larvae would be analyzed to find where exactly the waste is going during the waste reduction process. A feed conversion rate would be explored at different temperatures so manipulation of a system could be easily executed.

Ultimately, to prove the results can be scaled to Bell's volume, we must first have the manipulation of a BSF's lifecycle concrete. This includes a scalable compost bin design with zero faults as well as mastering breeding to continue the lifecycle for composting purposes.

⁷ Potential groups and individuals to collaborate with can be found in Appendix V.

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APPENDICES

APPENDIX I:

Contact List of Group Participants

Contact	Email	Phone
Leist, Alexandra	alexandra.k.leist@wmich.edu	248-884-5555

APPENDIX II:

External Contact List

Contact	Title	Email	Phone
Kanwischer, Derek	Coordinator of Sustainability Projects, WMU Office for Sustainability	derek.kanwischer@wmich.edu	(269) 387-0941
Modic, Walker	Sustainability Specialist, Bell's Brewery	wmodic@bellsbeer.com	(269) 250-8499
Shultz, Joshua	Permaculture Program Coordinator, WMU Office for Sustainability	cedarcreekpermaculture@gmail.com	(269) 331-0461

APPENDIX III:

Image Archives

- 1) Protapod™**
 - a. Top/side view**



b. Set-up at WMU



2) DIY BSFL Compost Bin

a. Set-up at WMU



3) Breeding Structure

a. Set-up at WMU



Appendix IV:

Screen shot of *BSFL Compost Bin Data Sheet*

HH1/ Compost Bins Data Sheet - March 2015

Date:	Sensor #:	1		2		3		4		5		6		7		8		9	
		T	RH	T	RH	T	RH	T	RH	T	RH	T	RH	T	RH	T	RH	T	RH
1-Mar	C					-	-												
	Max					-	-												
	Min					-	-												
	Compost Pile (F)					-	-	-	-			-	-	-	-	-	-	-	-
	Input (lbs)					-	-	-	-			-	-	-	-	-	-	-	-
	Leachate (mL)					-	-	-	-			-	-	-	-	-	-	-	-
	Pupae (lbs)					-	-	-	-			-	-	-	-	-	-	-	-
2-Mar	C					-	-												
	Max					-	-												
	Min					-	-												
	Compost Pile (F)					-	-	-	-			-	-	-	-	-	-	-	-
	Input (lbs)					-	-	-	-			-	-	-	-	-	-	-	-
	Leachate (mL)					-	-	-	-			-	-	-	-	-	-	-	-
	Pupae (lbs)					-	-	-	-			-	-	-	-	-	-	-	-

Appendix V:

Potential Collaborations

Contact	Location	Website
Agriprotein	Cape Town, South Africa; Gibraltar, Spain	www.agriprotein.com
Compost Mania	Dallas, TX, USA	www.compostmania.com
Enterra Feed	British Columbia, Canada	www.enterrafeed.com
Entologics	São Paulo - SP, Brazil	www.entologics.com
Enviroflight	Yellow Springs, OH, USA	www.enviroflight.net
Ofbug	British Columbia, Canada	www.ofbug.com
Protix Biosystems	Netherlands	www.protix.eu
Symton	PA, USA	www.symtonbsf.com
The Worm Dude	Southern CA, USA	www.thewormdude.com
Ynsect	France	www.ynsect.com

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