Whitten Family Farm

a case study

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Compost Exhaust Provides Nutrients for Plants and Heat for Greenhouse

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Project Summary

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This project sought to demonstrate that integrated compost and greenhouse production can not only be a synergistically beneficial endeavor, it can increase long-term farm viability by reducing heating and fertilizer costs. The outcomes of the composting process brings the added benefit of processing diverted food waste from landfills, increasing nutrient input to farms, decreasing heating costs, and increasing production leading to an increase in profitability and long term quality of life for farmers.

Primary Goals

1. Monitor and capture heat from the exhaust of active reverse aerated compost piles.
2. Demonstrate that captured heat will make it more affordable and sustainable to operate a greenhouse in cold climates.
3. Divert carbon dioxide, ammonia, methane and nitrous oxide in a biofilter before off-gassing into the atmosphere.
4. Record and analyze nutrient data to minimize formation and leakage of CH_4 and N_2O into the environment.
5. Understand the effects of exhaust nutrients on worms and plants.
6. Experiment with different biofilter mediums, plants and lighting arrangements to determine best practice for producing profitable and nutritious crops.

Project Description

The Whitten Family Farm (WFF) of Winthrop, NY was awarded grants in 2022 and 2023 to help construct a timber framed barn equipped with a reverse aeration composting system, 5 composting bays and an attached greenhouse.

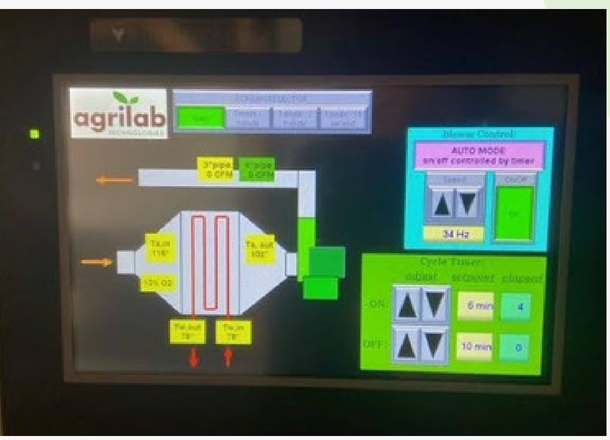
The bays are located on the north side of the building and are 12’ wide and 16’ deep. A perforated HDPE pipe runs through a 12” channel in the center of each pile, drawing air through the cooking compost piles which then passes through a manifold, heat exchanger and blower located inside the adjacent insulated building. Air exiting the active compost piles extracts moisture and nutrients from the decomposing microbial activity.

Some of the moisture is shed from the air as it leaves the channels under the bay, entering the cooler building as well as at the heat exchanger. Condensate traps collect moisture that is released at these points. Heat captured through the heat exchanger is used to heat the building and onsite water supply. After passing through the heat exchanger, warm, moist nutrient rich air is exhausted into a biofilter located in the ground on the south side of the building where a 12’ x 60’ greenhouse has been constructed.

The biofilter consists of 4” perforated HDPE pipe running in two continuous loops on either side of the center, covered in 24” of wood chips layered in the bottom of the greenhouse creating an aeration plenum. The plenum is covered by six inches of a soil and compost mixture as well as aragonite, zeolite, soft rock phosphate, biochar and bone char in zones, with the intention of understanding if certain supplements would help to bind excess nutrients.

Excessive accumulation of nutrients in growing matrices would be detrimental to crop health and yield, and the air quality within the greenhouse must be safe for occupants. We sought to not just minimize formation and leakage of CH_4 and N_2O into the environment but also to understand how to manage exhaust through a biofilter to positively affect nutrient availability and temperature for worms and plants.

The greenhouse atmosphere was monitored for CO_2 to optimize plant growth and control ventilation to ensure workplace health and safety. Worms (Eiseniia foetida) were introduced to help determine areas of excess nutrient buildup, assuming they would migrate away from nutrient concentrations. Crops grown included cucumbers, tomatoes, lettuce, and mixed greens.



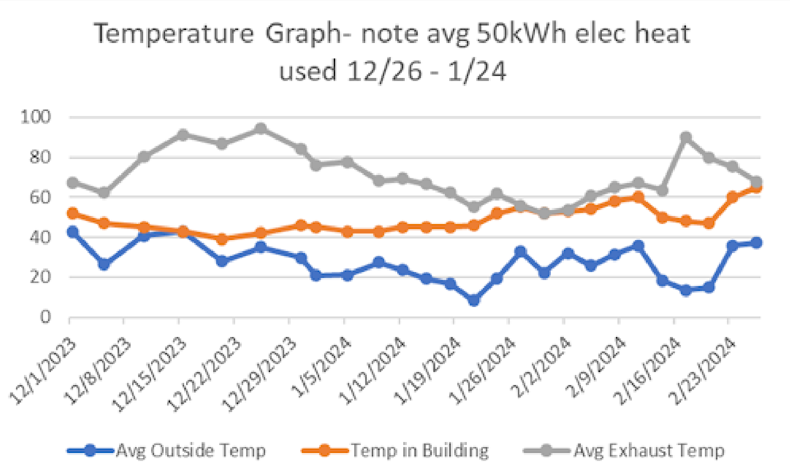
The biofilter was designed so heat, moisture and nutrients in the compost exhaust would move evenly throughout the substrate and then dissipate evenly into the upper layers. The biofilter made up the bed of the greenhouse which consisted of a polycarbonate angled wall and roof, creating passive solar heat gain for the building and a space for year-round growing with minimal to non-existent need for offsite heat. Lights were used to provide light during the short-days of winter, adequate to enable growth of crops.

To support project data collection, the reverse aeration composting system included a monitoring package supplied by Agrilab Technologies. It measures and records temperatures, aeration regimes, air flow rate and oxygen content of the compost exhaust. Additional monitoring equipment included a GL100 CO_2 data logger, an Ammonia Detector and Digital Refractometer to test for CO_2 levels in the air in and around the biofilter, ammonia in the compost bays, and leachate areas. A brix meter was used to measure the combination of sugar, amino acids, oils, proteins, flavonoids and minerals to reflect areas where nutrient buildup from the compost exhaust could be happening.

Project Results

During the winter of 2023-2024 the system was operating at 20% of designed capacity given a shortage of food scraps, our primary feedstock. The building and greenhouse required an average of 50 KWH in supplemental electric heat to maintain temperatures above 40F. Heat extracted from the composting process maintained higher temperatures during the warmer months of the season.

During the winter of 2024-2025, an increase in the volumes of compost processed resulted in the system operating at 34% capacity and warmer interior temperatures with nominal need for supplemental heat.



An electric hot water heater was used to boost temps for only 10 days between Jan 23rd & Feb 7th. Even without this boost, the building would likely not have gotten below freezing, but food waste bins in the building were too slow to thaw so needed the higher temperatures.

Tomatoes, cucumbers, lettuce and mixed greens were grown in the greenhouse biofilter. The initial crop of lettuce and greens produced high yields of healthy plants until it became too hot in April, with the lettuce not showing any indications of N excesses (eg tough leaves). A later crop of tomatoes and cucumbers did very well, with the cucumbers yielding exceptionally well, staying disease free for over a month longer than usual. During the winter of 2025 we were able to use supplemental lighting with lettuce yields of 40 pounds every seven days for four subsequent pickings, a very good regrowth rate, especially after more than two cycles.

At this time CO2 levels were elevated, ammonia was never detected and brix readings were consistently nondescript and average across the different biofilter bays. The lettuce never became tough as is known to happen with excessive nutrient input. There was no nutrient excess detected during this study, so we were unable to determine how biofilter amendments functioned.

Results Discussion

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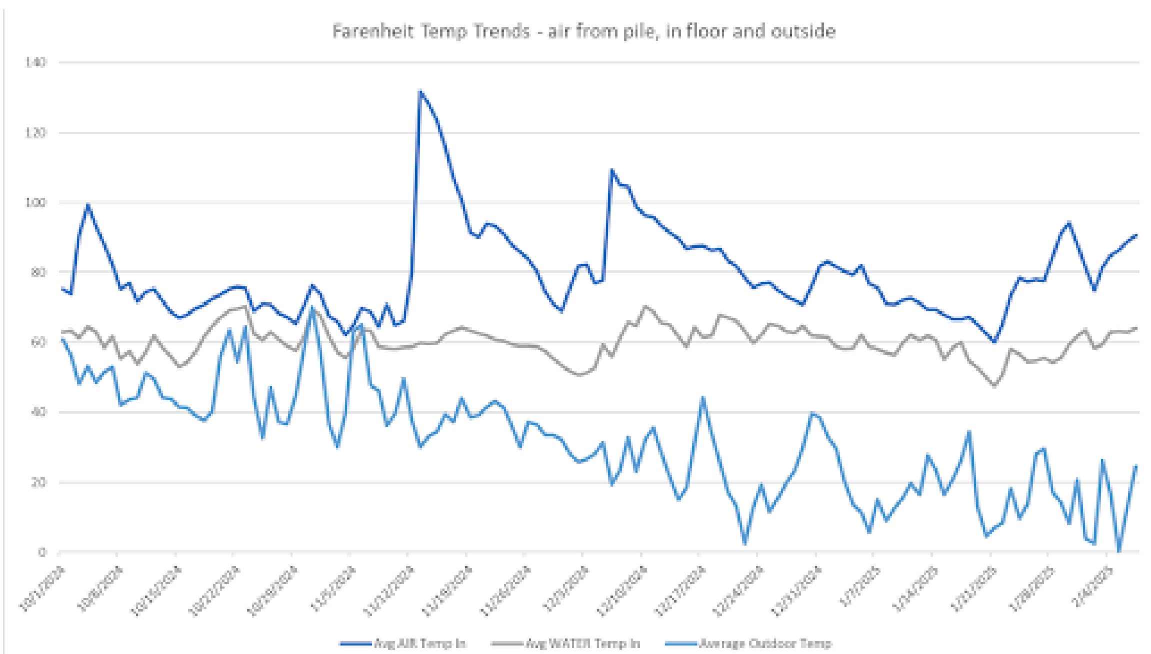
The minimal supplemental heating needed to maintain greenhouse temperatures at only 20% of capacity, shows that heating costs can be substantially reduced. In year 2 it was demonstrated that a system operating at 34% of capacity was adequate to keep an attached greenhouse above freezing.

We found that it would be difficult to operate at the intended design capacity even if sufficient food scraps were available. During cold weather, cold and frozen inputs required jumpstarting piles resulting in a slower temperature increase, and therefore increased cycling time. We also experienced mechanical and technical issues we did not foresee, which delayed loading or unloading the bays. The 2024-2025 food scrap volume of 9,713 is roughly 83% of what we now think is feasible for this design to handle. Our adjusted volume goal is 12,000 cf. We may find with more time, and better weather protection for the bays, that we will again increase that goal.



Due to lower-than-expected availability of compostable materials, the amount of exhaust and therefore nutrient levels is lower than anticipated, however, we did not change the bio-filter between seasons. It operated at 20% of project design capacity in year 1 and 34% in year 2. We surmise that the biofilter is capable of capturing most of the nutrients at 54% capacity. Based on the temperature data at 20% and 34% capacity, we could easily heat the building to much higher temps than recorded, however, it is difficult to quantify the saturation of nutrients at this lower-than-expected level. Although these numbers appear to be within reasonable range, there is still concern regarding the amount of CO_2 that could be emitted daily at higher feedstock volume levels.

Results Discussion Cont.

The highest CO_2 level reading was 4,930ppm above the biofilter area. This is approaching the 5,000 ppm maximum for 8-hour exposure, where there would begin to be safety concerns for exposure. CO_2 levels over 1,000 ppm enable increased photosynthesis efficiency leading to an increase in glucose production and faster growth rates, however this must be balanced with safety so this is an important factor to continue to observe.

The worms introduced into the biofilter were observed to have reproduced well and are found in all areas of the greenhouse in high numbers with no area devoid of their presence. They may have helped enable balanced conditions, as they could have digested some of the nutrients which may remain in a less volatile state.

Roughly 75% of plant and soil moisture needs were provided by the moisture contained in the exhaust piped into the bio-filter and root zone. Greenhouse gas emissions were offset as captured emissions were diverted to the biofilter whereas manually turning a compost pile results in fugitive gas escape to the atmosphere. We are unable to quantify the volume of GHGs offset given systemic limitations, however this is an outcome of the aerated static pile process that has been previously demonstrated.

Conclusions

1. Composting and greenhouse production can be mutually beneficial endeavors, diverting food waste from landfills while decreasing heating costs and reducing greenhouse gas emissions;
2. Anecdotal observation indicates an increase in crop yields and resistance to disease;
3. Resulting compost provides a local option for improved nutrient input on farms, increasing production and therefore profitability and quality of life for farmers.
4. Nutrient toxicity within the biofilter is unlikely with the building's functional capacity and with the current bio-filter design;
5. 400,000 BTUs of heat generated per day during the winter offset approximately 117kWh electricity, resulting in a savings of approximately $21.83 per day or $655/mo compared to electric heat; the blower and circulatory system cost roughly $140 per month, netting $515 in monthly savings;

   Tomatoes and cucumbers may be a better option for future plantings. Lettuce grown during the winter of 2025 was valued at $1,120, growing for a total of nine weeks. It is also cold hardy, where tomatoes and cucumber will not produce well if temperatures are not held above 50F. In retrospect, we now know that we were able to heat the building to above 50F for most of the winter, indicating that cucumbers and tomatoes might be better options. The 440 cucumber plants that were part of the mixed planting during the spring of 2024 were planted in two wide rows, using about 60% of the greenhouse space. They yielded 4,294 cucumbers over a six week early season period when they were worth between $1.25 & $1.75 each. This $6,595 harvest was a much more lucrative use of greenhouse space than lettuce.

By the Numbers

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The numbers in this table were calculated use 2024 pricing, exclude labor costs, and assume existing compost generation and food scrap collection services.

Cost of compost barn construction (self build v. contracted; with locally available materials)	$127K-$210K
ASP system - including monitoring system, heat exchangers, piping, and design (self install v. contracted)	$10,500-$21K
Grow lights to supplement dark months	$5K
Ammonia detector	$200
Red wrigglers - 50 pounds	$2K
Refractonmeter for brix measurements	$200
Biofilter inputs - Aragonite, Zeolite, Rock Phosphate, biochar and bone char	$700
Wood chips for biofilter	$300
Land improvements (including grading, electric, plumbing, clearing, etc.)	$10K-$20K

Recommendations

1. The compost bays were semi-protected with 3 sides and a roof which helped piles heat in the coldest weather. A door on the fourth side could help further.

2. Building the manifold to redirect exhaust from one pile into a new cold pile, enabled us to "jump-start" a pile in cold weather. Failure to heat a cold pile in mid-winter could result in inactive piles.

3. Further experimentations should include monitoring CO_2 and N_2O if possible, and particularly if there is reduced biofilter medium or increased exhaust, to ensure indoor air is safe for occupants.

4. We do not have automatic gates interacting with the Agrilab system, so need to manually adjust gate openings to vary air draw from different piles.

5. Automation would maximize heat capture when needed during the coldest winter nights, create the best composting conditions and increase feedstock throughput and capacity.

6. In the coldest weather, we sometimes slacked off on aeration in the afternoon, allowing heat to build in the piles, drawing extra during the night. This procedure was focused on heating the building, not the health of the compost. It was a minor deviation in aeration and we do not believe it harmed the compost.

7. We designed the exhaust pipes with the first section pitched back slightly towards the exchanger. This slightly reduced the amount of vapor and nutrients that reached the biofilter. This was adjusted slightly to a more shallow pitch after the first season. Because we never experienced an excess of moisture or nutrients we will pitch the entirety of the exhaust pipes forward in the future. I believe it was important that the exhaust system was built to enable the change of the pitch of the exhaust pipes. As richer hotter piles or larger quantities of compost vs biofilter area may require this.

8. The composition of the biofilter worked well for our application, and probably didn't need extra amendments, nor the depth of chips, however, this is speculation as we do not know if there would have been gaseous leaks or excessive nutrients otherwise. We should have varied the depth of the biofilter and used a control bay without amendments to try to determine this. We will continue growing in this biofilter and perhaps saturation will be reached, or perhaps, the plants are uptaking enough that this could balance perpetually. We did not consider that we could achieve a long term nutrient balance between the condensate nutrients and the plants, but it appears that may be possible. More studies should be done in this area.

Recommendations

9. We chose lettuce as a crop that responds quickly and obviously to excess nutrients. This is an appropriate crop as an indicator for studies, although it is not the most financially lucrative crop that can be grown. If high nutrient levels are present, other crops which utilize more nitrogen and increased light to help them photosynthesize would be appropriate.

10. Save money by pursuing grants and installing your own composting system.

11. Recommended future research:

    - Assess the impacts of vermiculture in a biofilter setting regarding nutrient balance;
    - Quantity the impacts on crop yields, vitality, nutritional content, resistance to pests and disease under controlled conditions;
    - Comprehensive cost benefit analysis expanded to include food scrap collection and compost generation;
    - With hoop house style greenhouses being more common and more affordable through the USDA EQIP program, future case studies could assess modifications needed to expand to this application.

Resources

- Agrilab - compost system design, consultation and installation
- James McSweeney Compost Technical Resources - multiple compost operator resources including a link to an online compost operator training program
- Compost for Good - compostforgood@adirondack.org; technical assistance and site visits; Compost to farm intake form
- NYS Soil Health Institute
- Composting Association of Vt, *On farm composting toolkit*
- Cornell Cooperative Extension Waste Management Institute
- USDA EQUIP - greenhouses- contact your local NRCS office
- Case study on hoop house application