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Supplementary Material

Performance of a Compost Aeration and Heat Recovery System at a Commercial Composting Facility

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The following supplementary material is included: **Table S1** Operational expense and energy use calculations; **Text S1** Assumptions used to determine operational expense and energy use; **Text S2** Management of composts by VNAP staff; **Text S3** Atmospheric Data Collection; **Text S4** NO_x-N produced and lost for each treatment; **Text S5** Potassium results; **Text S6** Detailed cost analysis figures; **Text S7** Fecal coliforms discussion.

Table S1: Operational expense and energy use calculations

	Conventional		CAHR	
m^3 finished compost	179		245	
Operational Activity	Financial cost ($)	Energy Cost (kWh)	Financial cost ($)	Energy Cost (kWh)
Compost Turning	$ 58.50	103.71	$ 52.00	92.18
Compost Watering	$ 20.00	17.73	$ 40.00	35.46
Aeration Blower Fan	$ -	0.00	$ 136.52	787.78
Total	**$ 78.50**	**121.44**	**$ 228.52**	**915.42**
Total (per m^3 finished compost)	**$ 0.44**	**0.68**	**$ 0.93**	**3.74**

Conversion Factors	
Liters/ gallon	3.7854
BTU/gallon	137381
kWh/BTU	3412

Compost Turning - Financial Costs	Turning events (ea)	Time/turn (hr/event)	Operator rate ($/hr)	Total Cost ($)
Conventional	9	0.108	$ 60.00	$ 58.50
CAHR	8	0.108	$ 60.00	$ 52.00

Compost Turning - Energy Costs	Turning events (ea)	Time/turn (hr/event)	Fuel use rate (L/hr)	Total Cost (kWh)
Conventional	9	0.108	10	103.71
CAHR	8	0.108	10	92.18

Compost Watering - Financial Costs	Watering events (ea)	Time/water (hr/event)	Operator rate ($/hr)	Total Cost ($)
Conventional	1	0.33	$ 60.00	$ 20.00
CAHR	2	0.33	$ 60.00	$ 40.00

Compost Watering - Energy Costs	Watering events (ea)	Time/water (hr/event)	Fuel use rate (L/hr)	Total Cost (kWh)
Conventional	1	0.333	5	17.73
CAHR	2	0.333	5	35.46

Aeration Blower Fan - Financial Costs	Estimated power draw (kW)	Hours run/day for study windrow	Days of study	Cost/kWh ($)	Total Cost ($)
Conventional	0	0	114	$ 0.17	$ -
CAHR	0.746	12	88	$ 0.17	$ 136.52

Aeration Blower Fan - Financial Costs	Estimated power draw (kW)	Hours run/day for study windrow	Days of study	Total Cost (kWh)
Conventional	0	0	114	0.00
CAHR	0.746	12	88	787.78

Phase II construction - Financial Costs			
Total HB2 Cost	Cost/yr (15 yrs)	m^3/yr	Cost/m^3
$ 243,623.00	$ 16,241.53	4283	$ 3.79

Text S1: Assumptions used to determine operational expense and energy use

To determine operational expense and energy use, the following assumptions were considered:

- Compost turning with the Komptech Topturn x53 straddle turner
  - 10 L/h fuel use during turning, provided by VNAP
  - 6.5 minutes to turn a 61m (200') windrow, provided by VNAP
  - $60/h operator wage, provided by VNAP
  - 9 turning events for the conventional windrow
  - 8 turning events for the CAHR windrow
- Compost watering with a 16.7 m^3 (4400 gal) liquid manure tanker
  - 5L/h fuel use during watering, estimated as half of turner fuel use rate
  - 20 min to fill and dispense 16.7 m^3 of liquid leachate, timed by FB
  - $60/h operator wage, provided by VNAP
  - One watering event of 16.7 m^3 for the conventional windrow
  - 2 watering events of 16.7 m^3 for the CAHR windrow
- Aeration by the CAHR system
  - 746 watt (1 hp) power draw by the aeration fan, provided by Agrilab Technologies
  - 12 h of aeration for the CAHR test window/day, considering that the CAHR windrow spanned 2 aeration zones, each of which were aerated 25% of the time.
  - 88 days of aeration for the CAHR test windrow
  - 17.33 cents/kWh average commercial electric rate in VT, USA, provided by US Energy Information Administration (EIA)

Text S2: Management of composts by VNAP staff

Management of compost windrows by VNAP staff did not rely on tested metrics such as lab-tested moisture content or C:N ratio. Rather, staff relied on daily temperature measurements, weather observation, and visual, textural, and olfactory inspection skills gained from decades of compost management experience and nationally respected training programs (e.g., Maine Compost School). Typically, VNAP staff would use a front-end loader to cut out a portion of a windrow for inspection. By using the CAHR system's graphical user interface, VNAP and Agrilab Technologies staff were able to visualize historic and real-time aeration rates, vapor oxygen concentration, and vapor and heating system temperatures. Aeration rates and durations could be set for each zone of the system, allowing staff to fine-tune oxygen supply.

Text S3: Atmospheric Data Collection

An Onset HOBO UA-003-64 data logger and tipping bucket rain gauge were deployed on August 24, 2021, concurrent with the beginning of the sampling period. Data were downloaded from this logger on September 24, November 1, and December 29. Rainfall during a short period between October 30 and November 1 was not recorded by the HOBO due to file size limits being exceeded. Rainfall data from the nearby Middlebury State Airport (approximately 2.4 km SE) was sourced from the National Oceanic and Atmospheric Administration's Climate Data Online Search to fill this data gap.

An Onset HOBO external temperature and relative humidity sensor was deployed from October 7, 2021, to December 8, 2021. Hourly temperature data from the nearby Middlebury State Airport were sourced from the

National Oceanic and Atmospheric Administration's Climate Data Online Search to fill the August 24 – October 7 and December 8 – December 15 data gaps.

Text S4: NO_x-N produced and lost for each treatment

Through week 13, the conventional windrow produced an observed 6.43 g NO_x-N/kg and lost 5.60 g NO_x-N/kg. During the same period, the CAHR windrow produced an observed 6.50 g NO_x-N/kg but lost only 2.10 g NO_x-N/kg.

Text S5: Potassium results

Potassium (K), a vital nutrient for plants, was also analyzed in this study. Initial K concentrations for the conventional and CAHR windrows were 1.2% and 1.3% respectively, and total K concentrations both composts trended nearly identically through the duration of the study period. Overall, the conventional treatment resulted in marginally greater concentrations of K than CAHR treatment (2.5% and 2.3% respectively), likely due to the extended composting duration. No by-week or aggregate significant differences were found for K between the treatments through week 13 ($p > 0.05$).

Text S6: Detailed cost analysis figures

The relative operational cost of \$0.49/m^3 for the CAHR system was calculated by taking the difference between the operational costs for the CAHR (\$0.93/m^3) and conventional (\$0.44/m^3) treatments, found in the bottom row of Table 3. Capital expenses for construction of the CAHR system used in this study were \$243,623.00, and an estimated 4283 m^3 (5602 CY) of compost can be processed per year with this system per Foster et al. (2018). Spreading the capital expense over an estimated system longevity of 15 years, we calculated a \$3.79/m^3 (\$2.90/CY) expense for installation of the CAHR system.

Text S7: Fecal coliforms discussion

Fecal coliforms increased over the study, which is surprising, namely for the CAHR system, which provided higher consistent temperatures and potential for pathogen kill. Because fecal coliform data were only obtained for the first few and last samples of each treatment, we were not able to visualize trends. Increases in fecal coliform data could have arisen from a few sources, namely high bird activity at VNAP, localized high levels of coliforms that happened to be randomly sampled, and any pathogen growth between when samples were shipped from UVM to when they were analyzed at A&L Labs. Indeed, variable pathogen levels have been detected in different areas of compost volumes (i.e., surface vs. interior samples) (Sharma and Reynnells 2018; Shepherd et al. 2010), and sampling from a localized area of contamination may have influenced our results. Interestingly, like our final CAHR results, composts sampled by Ingram (2009) in late fall were found to have higher pathogen content than those sampled in other months. Pathogen regrowth in composts stored in plastic bags has also been documented (Reynnells et al. 2014) and has been related to moisture content, C:N ratio, and TOC of sampled composts. While determining pathogen origin was not included in this study, it is likely that windrow surface contamination or pathogen regrowth resulted in the higher levels of fecal coliforms in our final samples, especially considering that both treatments sustained internal temperatures sufficient for pathogen kill.

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