Effect of Fiberware and PLA Compostables on Compost Maturity via Greenhouse Gas Emissions

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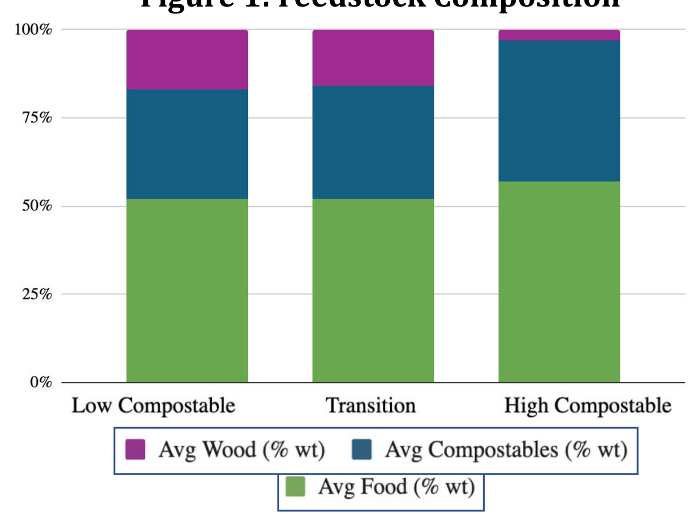
Introduction

- Princeton's S.C.R.A.P Lab has experimented with the implementation of varying levels of compostables in the feedstock for composting to understand their environmental impact and compost viability.
- (1) Weeks 1-3 treatment cycle: Low compostable treatment
  - 30-35% compostables, 15-20% wood shavings, remainder food waste
- Transition: Feedstock offloaded
- (2) Weeks 4-6 treatment cycle: High compostable treatment
  - 37-42% compostables, 0-5% wood shavings, remainder food waste

Figure 1: Feedstock Composition



- Composting promotes microbial digestion of food and other organics, reducing net greenhouse gas (GHG) emissions versus landfills (Deesing, 2016)
- However, composting still produces GHGs, and CH_4 and N_2O emission rates are especially important to consider as the primary drivers of net climate forcing from composting (Nordahl et al., 2023). The Global Warming Potential (GWP) of CH4 is 27-30 times of CO_2 and the GWP of N_2O is 265-298 times that of CO2 over 100 year period, indicating an importance to limit their emissions in the composting process (EPA, 2024).
- The compostables used consist of primarily sugarcane bagasse and PLA (polylactic acid); the former is more prevalent than the latter. The change in carbon source by the addition of feedstocks may affect the composting process.

Research Focus

Research Question: How do GHG emissions reflect decomposition rates and compost maturity across different feedstock compositions of high and low compostable treatments?

Hypothesis: A high compostable treatment leads to more mature compost and faster decomposition rates and thus promotes local zones of anaerobic microbial processes, leading to more CH_4 and possibly N_2O production.

Methods

Composting
Feedstock processed using Princeton's Model 1000 Aerobic In-Vessel Rotary Drum system with a processing capacity of 2268 kg/week installed in 2018

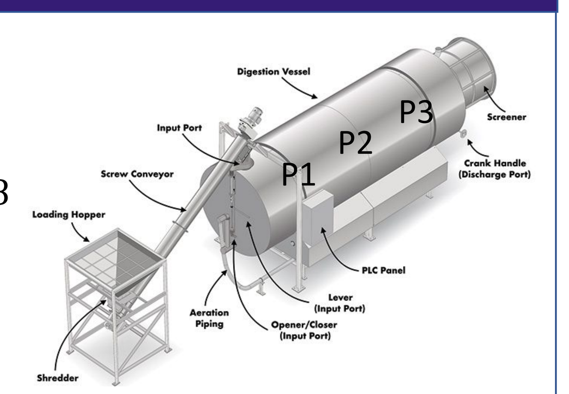


Figure 2: AIVRD vessel system used in S.C.R.A.P Lab, with Ports P1, P2, P3.

CO_2, CH_4, and N_2O Emissions:
Picarro G2508 GHG Concentration Analyzer took real time measurements of CO_2, CH_4, and N_2O from exhaust port gas emissions in ppm.
Data was standardized by weight in kg of feedstock.

CO_2 Incubation Production Rate:
Two 40 gram samples of compost from each port were measured over 1000 seconds using the Vernier Go Direct CO2 Gas Sensor Probe weekly

Particle Size:
Compost samples were outsourced and tested by Agro Lab through sieving

CH_4 Emissions per port:
3 mL of headspace has was collected in triplicate from each port of difester and stored in 12.5 mL vial. Samples analyzed on Shimadzu GC and results were standardized with known concentrations and by weight in kg of feedstock.

Nitrate Leachate:
20 grams of homogenized dry compost and 400 mL of DI water were mixed for 5 min. at 180 RPM. A 0.22 µm filter was used to filter leachate. 40 mL and 10 mL samples were run triplicate in NO_x box to determine nitrate concentration based on known concentrations in potassium nitrate standards. Error bars are the 1 SD (std. deviation)

Results

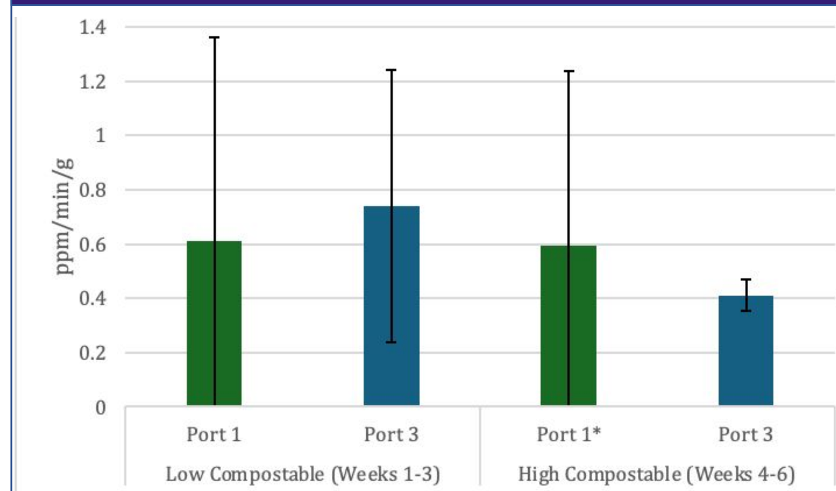
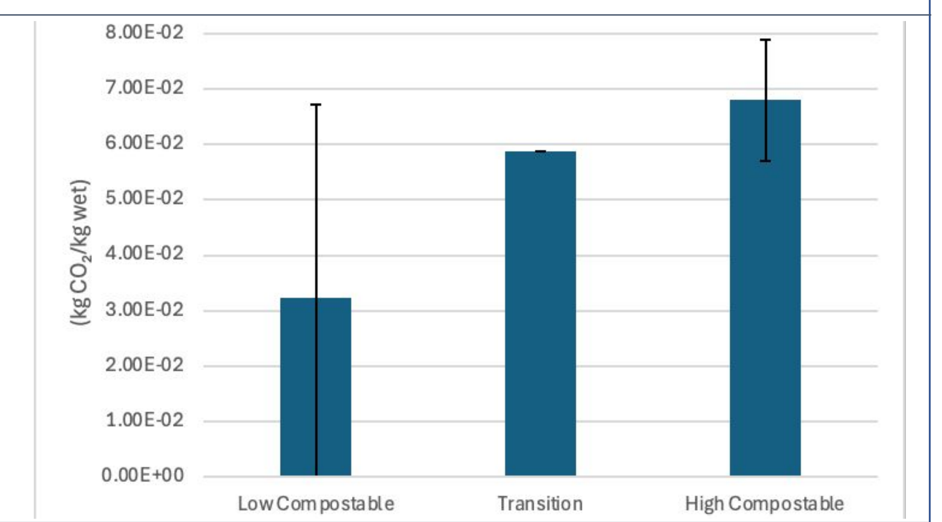


Figure 3: Incubation CO_2 production rates
*Port 1 data was not available for Week 4
High variability in Port 1 across treatments. Lower production, variability in Port 3 with high compostables.

Figure 4: Average weekly in situ CO_2 emission factor
Increase in CO_2 levels in treatment 2 with high compostables, high variability of levels in low compostable treatment 1.



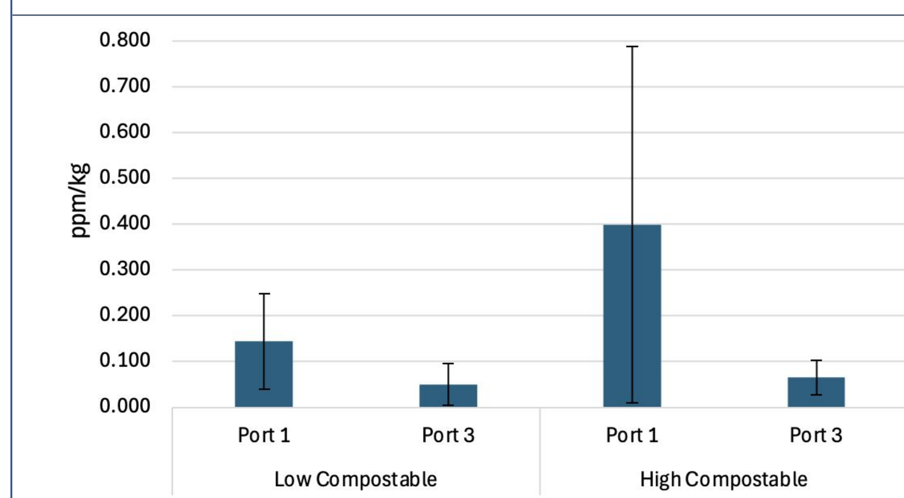
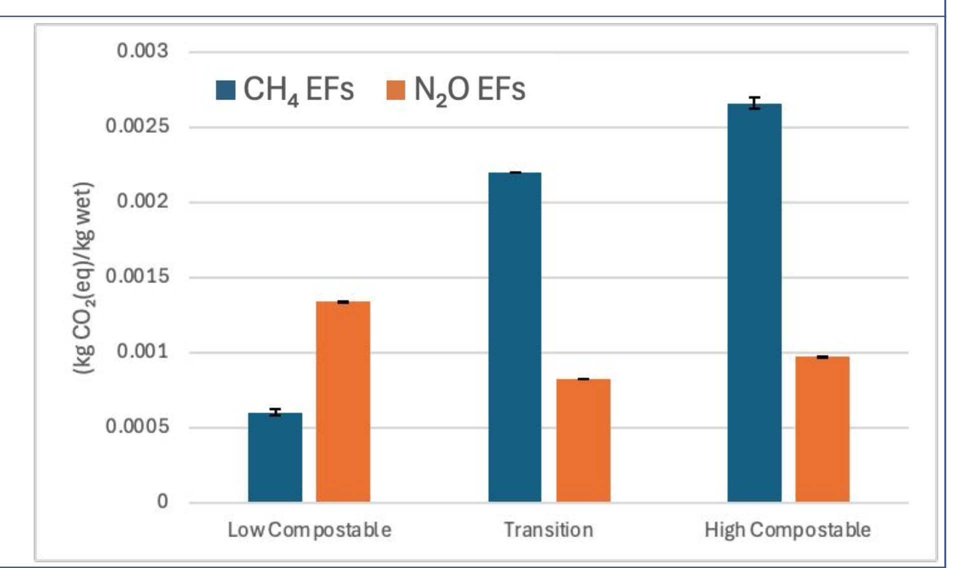


Figure 5: Average CH_4 production rate in ppm per kilogram
Higher production in Port 1 in high compostable treatment.
Port 3 production similar across treatments.

Figure 6: Average CH_4 and N_2O emissions factors in CO_2(eq)
CH_4 emissions increase, N_2O emissions decrease with higher compostable content.



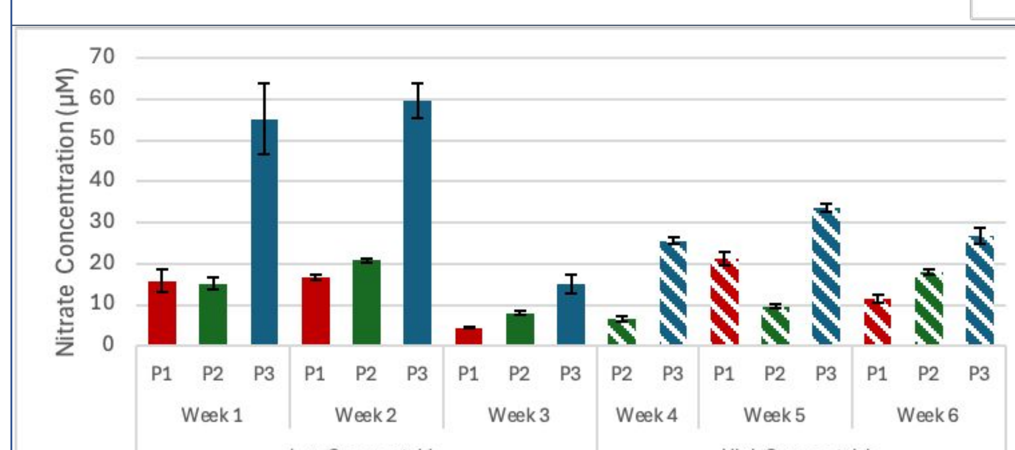
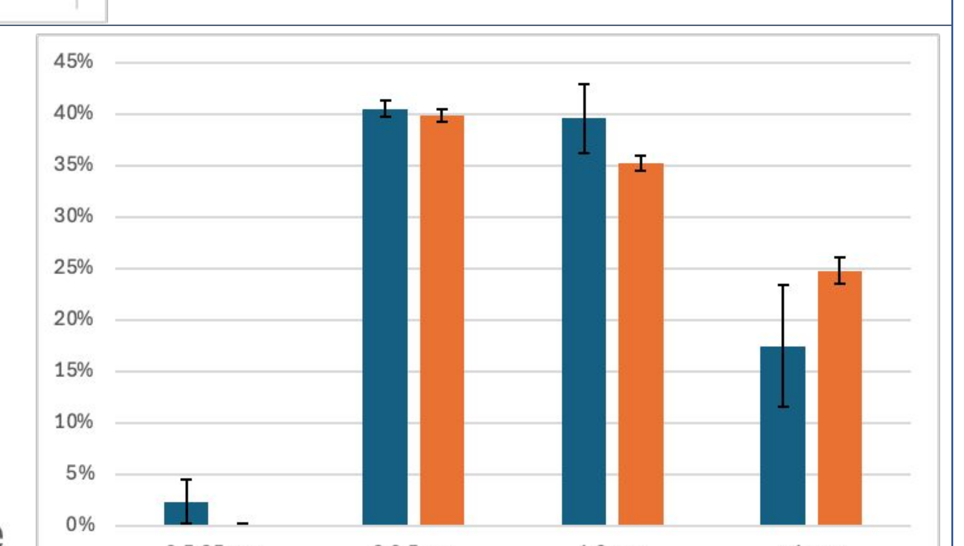


Figure 7: Compost Nitrate
Increased N_3O levels in low compostable treatment across ports.

Figure 8: Average particle sizes in compost
Particle sizes tend smaller in higher compostable treatment.
*Data not available for Week 6

Low Compostable High Compostable



Discussion

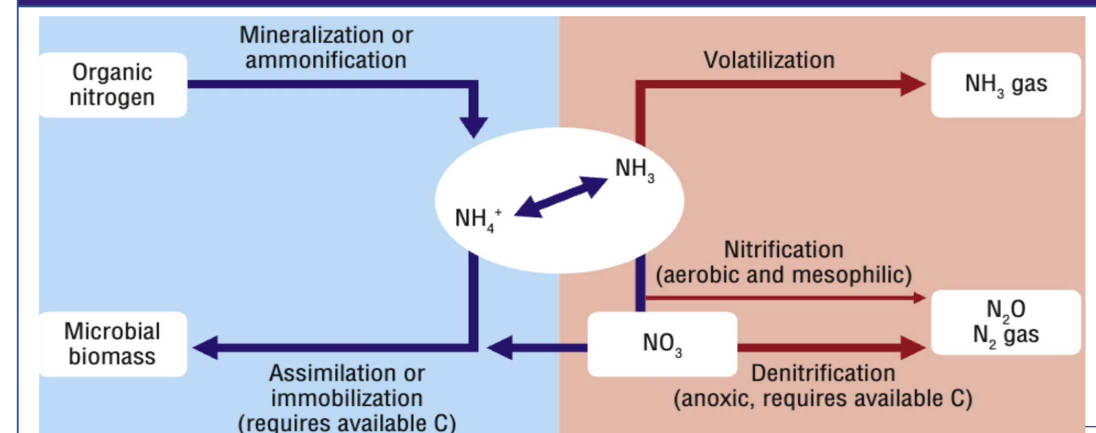


Figure 9: Nitrogen dynamics during composting (Rynk et al., 2022)
N_2O producing processes, e.g. nitrification, denitrification, favored by less carbon-rich, less aerobic conditions.

The research findings showed an increase in CH_4 and decrease in N_2O emissions in the second treatment, with high levels of compostables in the feedstock, proving our hypothesis partially incorrect as it was predicted N_2O levels would increase; however there were higher levels of CH_4 and stronger indicators of maturity, as hypothesized.

N_2O:
N_2O levels were higher in the low compostable treatment (Fig. 7) because there was insufficient nitrogen available for microbes to use due to a limited amount of useable carbon in the feedstock from the wood. This led to an increase in ammonia converting to nitrate as it could not be taken up by microbes into their biomass and nitrification occurred (Fig. 9), leading to a rise in N_2O (Fig. 7). In the high compostables treatment there was more carbon available, as the compostables are easier to degrade than wood due to wood's high lignin content (Bjordal and Dayton, 2020), which prevented nitrification and instead promoted the uptake of nitrogen into microbial biomass.

CH_4:
In the low compostable treatment, the carbon provided by the wood was not as easily degradable leading to less CH_4 per kg production (Fig. 6). Meanwhile in the high compostable treatment the carbon in the compostables is more degradable leading to higher carbon availability which promotes decomposition at faster rates increasing the usage of oxygen. This possibly leading to anaerobic conditions, as seen by the higher CH_4 levels in Port 1 in the high compostable treatment (Fig. 5). Observing that Port 3 CH_4 is similar across treatments (Fig. 5), we can also conclude that more of the anoxic conditions for CH_4 production in the high compostable treatment exist in Port 1.

CO_2 on Compost Maturity and Rate:
The high variance in Port 1 CO_2 production (Fig. 3) can be attributed to a "startup" period when SCRAPPY is first being loaded. The decreased variance in Port 3 in the high compostable treatment, with a lower (albeit not statistically significant) rate of production (Fig. 3) shows stability typically indicative of more mature compost (Yang et al., 2019). In tandem with more CO_2 emission factor in situ (Fig. 4), this indicates that there is more microbial activity and so a faster composting process, justified as there are more compostables and less wood, which is harder to degrade (Bjordal and Dayton, 2020). The generally smaller particle sizes (<10 mm) in high compostable treatment, (Fig. 8) also indicate increased compost maturity (Stehouwer et al., 2022).

Conclusions

Use of compostable fiberware and PLA in place of wood for C/N balance and bulking in compost, led to higher decomposition rates, thereby higher greenhouse gas emissions as the carbon in the compostables was more degradable, leading to faster maturation.

- A more robust aeration process may be able to offset anoxic conditions in high-compostable compost and therefore reduce CH_4 emissions and consequently net emissions factors. The higher CH_4 emissions localized to Port 1 suggest that it may be valuable to look into methods of feedstock preprocessing to minimize these pockets.
- Based on the effect of sugarcane bagasse to increase composting rate and maturity, it may be valuable to explore exhausted grape marcs (EGM), which compound with bagasse to reduce composting time to as low as 21 days (Zhang and Sun, 2016).
- Though this study has demonstrated key aspects of the composting process that are in line with the literature, the low sample size and time resulted in an inability to conclude significance, so this study was not exhaustive; significant differences in maturity and emissions may become apparent in a longer-term study. We suggest that future research of this kind uses samples over a time frame of several weeks to allow for more meaningful statistical tests and consequently stronger results.

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