Earth Foundries, Inc.

August 23, 2023

FINAL REPORT: CO-COMPOSTING BIOCHAR AT NAPA RECYCLING IN AN UPFLOW COVERED AERATED STATIC PILE (CASP) ENGINEERED COMPOSTING SYSTEM (ECS)

This project aimed to demonstrate the economic value of co-composting Biochar with a mix of green and food waste feedstock in a commercial CASP composting system. The project obtained numerous data points over one composting cycle featuring measurements of non-methane VOC (Volatile Organic Compounds) emissions, compost (soil) nutrient analysis, maturity, and pathogens for a Biochar treatment and Control pile. The tests were completed at Napa Recycling in American Canyon, California, running from June 12 through August 2, 2023.

Key findings:

1. Biochar co-composting reduced non-methane VOC emissions, a feature of biochar that can be used to increase compost facility throughput under permitted VOC emission levels. On average, adding ten volume percent of Biochar from forestry residuals to the green and food waste feedstock reduced VOC emissions by 33% across the composting cycle.

2. Biochar reduced the curing time required to achieve compost maturity. Biochar treatment reached low levels of free ammonium in the compost one week sooner than the Control.

3. Adding Biochar increased the NPK value of the finished compost. The NPK value of the finished compost increased by 11% in this test relative to the Control. The biochar imparted a time-release property to some of the nutrients in the finished compost.

4. Biochar treatment reduced the salinity of the finished compost. The concentration of calcium and magnesium salts in the finished compost decreased by over fifty percent in the soluble extract.

This study featured the first and successful use of a simplified version of EPA Method 25.3 named R-25 for measuring the flux of non-methane Volatile Organic Compounds (VOC), enabling the low-cost acquisition of a large amount of data.

BACKGROUND

Composting occurs in three phases: thermophilic (high temperature, rapid decomposition), mesophilic (moderate temperature, continued breakdown), and curing (ambient temperature,

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maturation). These stages, driven by different microbial communities, convert organic materials into nutrient-rich compost.

There are two types of composting systems: Windrow and CASP. For Windows, a green feedstock pile is created from ground materials and is not covered. The compost pile is turned for aeration purposes and watered every five days. In CASP systems, the air is blown into the pile continuously, from the bottom up, or drawn through it from the bottom, so turning is not required to achieve aeration.

There are three types of CASP systems. The first is an up-flow CASP system, where finished compost is placed on top of the composting pile to capture emissions. The second is an up-flow system where the pile is covered using a synthetic cover. The third type draws air through the bottom of the compost pile and into a biofilter to remove emissions. ECS (Engineered Composting Systems) supplies the uncovered and biofilter systems, and Gore (as in Gore-Tex) provides the covered systems. Napa Recycling utilizes up-flow ECS CASP systems.

CASP systems can complete composting cycles in shorter times than Windrow systems due to the continuous aeration and are better at mitigating odors and VOC emissions. CASP systems are almost exclusively used outside major metropolitan areas in California (nonattainment) due to lower emissions, reduced odors, and the economic benefit of shorter composting times and faster tipping fee capture.

VOC emission quantities are regulated because they interact in atmospheric chemistry to produce ground-level ozone. Ozone is a respiratory irritant that can lead to various human health problems, such as asthma, and is known to exacerbate cardiovascular diseases. Ozone can also reduce crop yields and impair the growth and health of plants and trees, with a cascading deleterious impact on entire ecosystems.

Because composting systems in California are permitted based on total allowable VOC emissions, reducing emission quantities enables increased throughput and tipping fee capture. The compost business in California is financed through tipping fee capture almost exclusively. Composting is mandated by Senate Bill 1383, requiring the diversion of green waste from landfills to mitigate methane greenhouse gas emissions so that green and food waste can be collected at their origins, where fees are collected.

By regulation, in addition to VOC emission limits, a compost operation must achieve PFRP (Process for Removing Pathogens) by operating above the temperature of 40 °C (131 °F) for a specified period. For Windrows, they must operate for at least 15 days; for CASP systems, it is

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only three days. Therefore, the opportunity to reduce cycle times is greatest for CASP systems if VOC production can be significantly curtailed.

Mature and stable composts have low ammonia and CO2 evolution rates. Users prefer to use mature composts because when applied to the soil, immature composts can compete with plants for nitrogen, starving the plant of nutrients. Regulators do not require compost to be mature.

Previous studies of biochar co-composting report reduced VOC emissions in laboratory and small-scale windrow composting by incorporating biochar. The literature suggests that the reduction in VOC emissions can be attributed to the sorption of VOCs by the Biochar and by mitigating the anaerobic conditions within the compost pile by adding air porosity. Researchers have also shown that adding Biochar reduces the time required to achieve compost maturity, as evidenced by achieving lower extractable ammonium sooner. Composts produced with Biochar have also been reported to enhance plant growth.

Unfortunately, the published studies of co-composting biochar are limited to Windrow systems, and measurements completed on CASP systems are unavailable. The published studies are mostly conducted on the laboratory or smaller farm-scale systems, avoiding the inherent variability of commercial systems. This variability originates from non-uniform feedstock sources, incomplete mixing, variable and dynamic aeration, and non-uniform hydration.

The foundation of the study is the use of the scientific method. The scientific method requires claims to be based on measurements and repeatable data. Large amounts of data were collected in the study to enable piercing through the variability in data from the commercial system; for instance, 255 measurements of VOC levels were made. Statistical analysis using the R programming language was used to determine if the averages between data sets differed and if the data spread was narrow enough to confirm a claim and answer the posed questions.

RESEARCH QUESTIONS

The objectives of this commercial demonstration – questions to be answered, were agreed to in consultation with Earth Foundries, as follows.

1. Does adding ten-volume percent biochar (produced from forestry waste using a Carbonator biochar machine) to a green and food waste pile (80:20 by weight) reduce VOC emissions from a CASP composting system?
2. Does adding Biochar reduce the time to maturity as measured by exchangeable ammonium and cucumber emergence bioassay?

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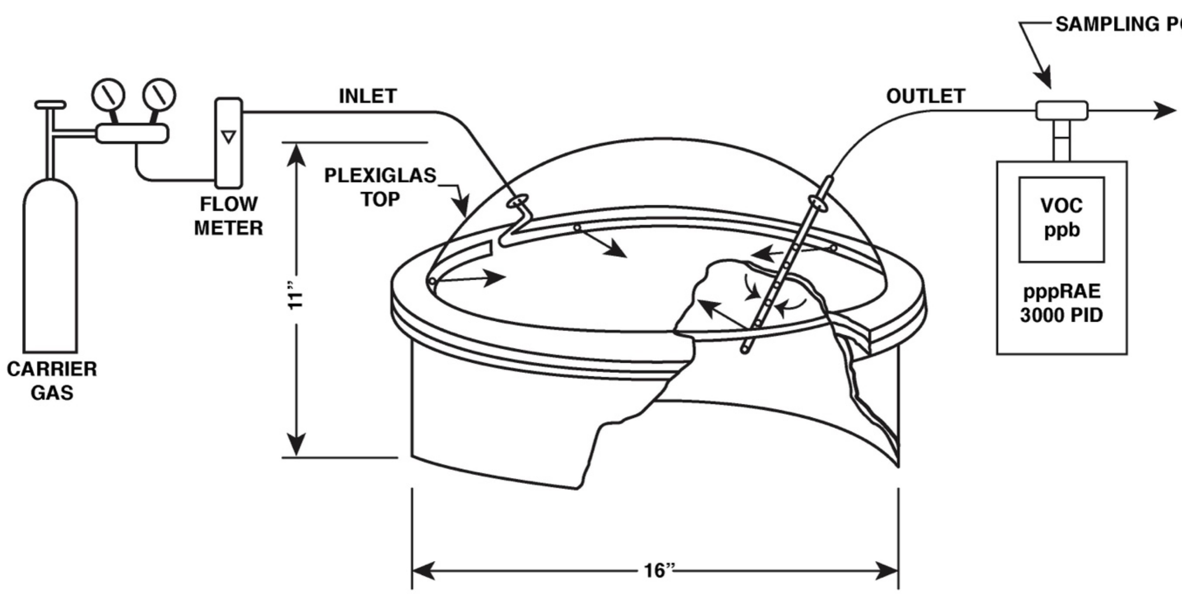
3. Does adding Biochar improve nutrient availability and reduce the finished compost's salinity (ECE and chloride)?
4. Does adding Biochar reduce the C/N ratio of the finished compost, adjusting for carbon addition from Biochar?
5. Does the use of biochar impact pathogen reduction?
6. Does mixing Biochar in green waste produce a greater exotherm relative to Control?

METHODS

Non-Methane Volatile Organic Compounds (VOC)

R-25: Our method for determining VOC fluxes, developed by the principal investigator, represents a dramatic simplification of EPA Method 25.3 for measuring the flux of non-methane Volatile Organic Compounds (VOC). The inert nitrogen carrier gas is metered into an emission flux chamber placed on top of the compost cap of the compost pile as per Figure 1. The measured concentration of VOCs, the carrier gas flowrate, and the surface area of the flux chamber are used to calculate flux rates (milligrams per square meter per hour)

Figure 1: VOC Measurement Equipment



This approach features a hand-held Photoionization Detector (ppb RAE3000 PID) developed by Honeywell, capable of directly measuring VOC concentrations at parts per billion levels in the field without interference from the other gases in the mixture such as CO2 and CO, greatly simplifying

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the test method. From the measured concentrations and gas flow rates, the site can directly measure the flux of VOC (and Ammonia if desired) from a compost pile, significantly reducing the cost of acquiring emissions data relative to a hiring Source Testing company to do the measurements. The EPA has not approved (or disapproved) using R-25 for emissions permitting and is only suitable for research purposes currently.

(Soil) Nutrient Analysis

Figure 2 describes the Soil Nutrient Supply consisting of Total, Extractable, and Soluble Nutrients. Extractable nutrients are a subset of Total, and Soluble is a subset of Extractable. The techniques for isolating and analyzing these components are as follows.

Dry Combustion Elemental Analysis method analyzes carbon and nitrogen content in determining the C-to-N ratio (C/N) in Total. The release rate of Total Nitrogen to the plant depends on the C-to-N ratio, with lower values favoring nitrogen mineralization into usable forms.

The ***Nitric Acid*** method measures "total nutrients" other than nitrogen, i.e., those expected to be released over a year or more timeframe.

The ***Ammonium Bicarbonate / DTPA*** method measures "available nutrients," i.e., those expected to become available to the soil in less than a year.

The ***Saturated Extract*** method measures nutrients and contaminants soluble in water and will be immediately available to a plant. This test also includes ECE (electrical conductivity – a measure of salts), chlorides, and pH as seen by the soil.

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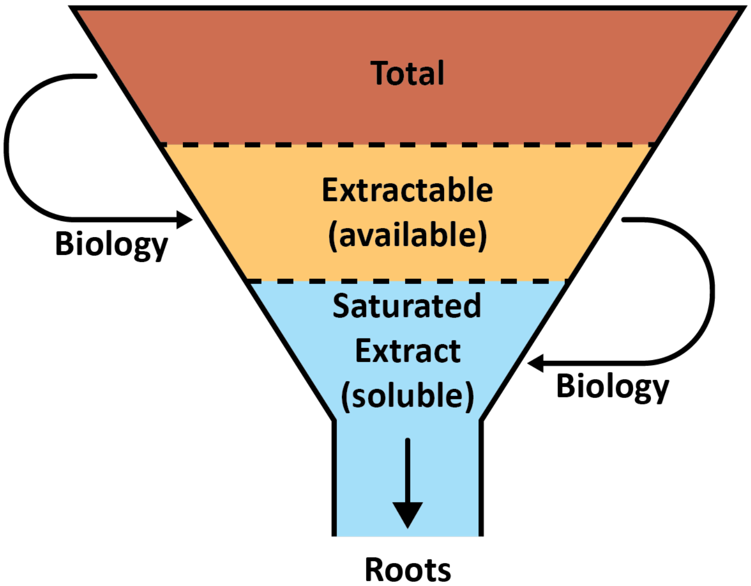
Figure 2: Soil Nutrient Supply



The ***Free Ammonium Extraction*** method with potassium chloride was used to extract free ammonium ions, which were then analyzed using spectroscopy.

Wallace Laboratories in El Segundo, California, was used to complete these analyses, along with measurements of the physical properties of the compost.

Pathogens and the Cucumber Emergence

The compost biological parameters were determined using the compost Seal of Testing Approval methodologies by their approved laboratory, Soil Control Laboratories in Watsonville, California.

The pathogens testing included salmonella and fecal coliforms. Salmonella is the most reported cause of foodborne illnesses. Fecal coliforms are indicator bacteria indicative of the possibility of toxic bacterial vectors.

Soil Control labs in Watsonville, California, were used to complete these analyses.

SITE OPERATIONS

The test lasted 51 days, 35 days in the bunker with aeration available, and 16 days in curing. The test schedule is presented in the Appendix.

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Biochar

A Tigercat Carbonator was used to produce biochar from forestry waste through a grant to Earth Foundries. An analysis of the biochar is presented in Table 1.

Table 1: Biochar Analysis		
Bulk Density, #/CY	327	pounds/cy
Moisture	68	% of total weight
Dry Density	105	pounds/cy
Organic Carbon	86.6	% total
C/N Ratio	152	
Hydrogen to Carbon	0.20	Molar Ratio
pH	11.16	
Liming	9.6	% CaCO3
Surface Area Correlation	467	m2/g dry
Volatile Matter	8.6%	percent dry weight
Particle Size Distribution		
<0.5 mm	2.2	percent by ASTM D 2826
0.5-1 mm	1.1	percent by ASTM D 2826
1-2 mm	2.9	percent by ASTM D 2826
2-4 mm	8.9	percent by ASTM D 2826
4-8 mm	24.6	percent by ASTM D 2826
8-16 mm	60.3	percent by ASTM D 2826
> 16 mm	0	percent by ASTM D 2826

This biochar is high in carbon and high in pH. The high Surface Area correlation value indicates that the internal pore structure of the underlying biomass is largely preserved, benefiting its overall expected performance as a soil amendment. Note that the particle size of this material is skewed towards the larger distribution size relative to most soil amendments. Most soil amendments are sized between one-half and four millimeters. 84.9 percent of this material is sized above four millimeters, reducing the surface area available for chemistry relative to its mass.

Feedstock Preparation, Mixing and Loading

The base feedstock at Napa Recycling is 80% green waste and 20% food waste by mass. To prepare the biochar-containing feedstock, dump trucks were loaded with the green and food waste-based feedstock, and biochar was added to it at a ratio of 9 loader shovels of green food

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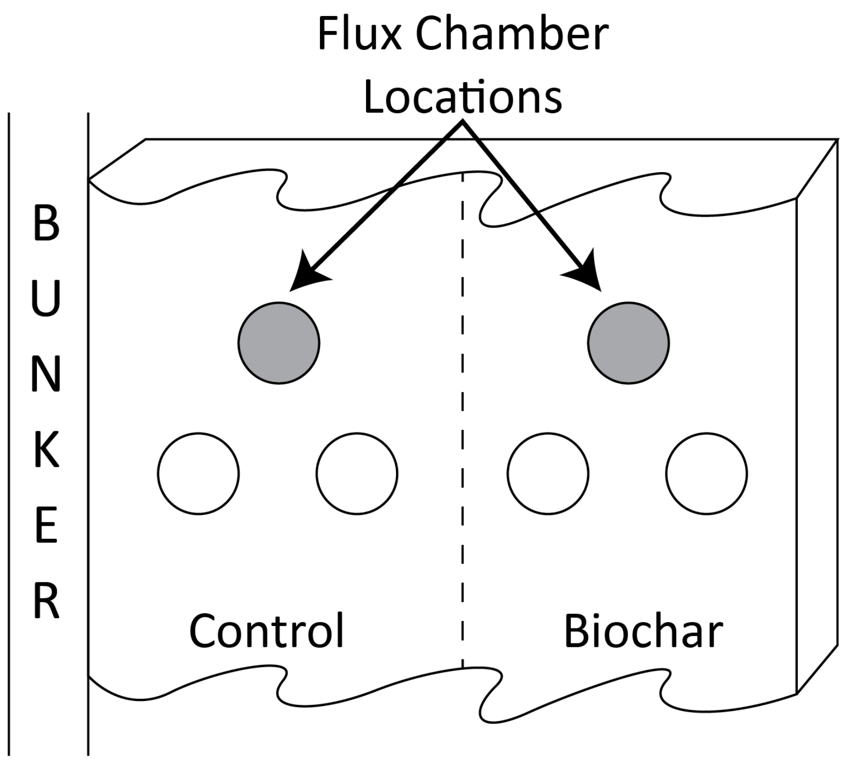
waste to one shovel of biochar. This material was moved to a mixing pad, and the loader was used to integrate the Biochar into the green waste material on a mixing pad by rolling and flipping.

Half of the compost bunker was loaded with biochar blend and half control, approximately 450 cubic yards of each material, for a total of 900 cubic yards. The layout of the bunker and the VOC sampling locations using the flux chamber is shown in Figure 3.

Figure 3: Layout of Bunker Testing Points



The bunker was loaded with the feedstock arranged as per the loading diagram. Six inches of finished compost was added as the compost cap on the raw feedstock.

VOC Measurements

The gas cylinder containing compressed nitrogen should be located at ground level and on its side. The gas cylinder was connected to the pressure regulator. One end of the 100 feet tubing was connected to the pressure regulator and the other to the flow meter. The gas cylinder valve is opened with the flow meter turned off, and the regulator outlet pressure is set to 35 psig.

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The technician firmly pushes the flux chamber into the compost cap to minimize leakage out of the sides. The ppbRAE moisture trap was replaced at the beginning of each daily testing session. Once connected to the flux chamber, the gas flow should be opened at the flow meter, and the rate set to 3-10 liters per minute. After five minutes, the operator inserted the ppbRAE into the vent port and recorded the VOC concentrations and flow rates at one-minute intervals for five minutes by taking photos and uploading them onto the project OneDrive.

Three flux chamber measurements of VOC concentrations will be completed for the control and biochar treatments using a single flux chamber moved from location to location for six. The diagram shows that the flux chamber should be relocated at about equal spacing across the compost heap for each new measurement. When reinstalled, the operator should not use the exact position previously used when placing the flux chamber.

Compost Sampling

While in the bunker, the compost cap was dug out about two feet below the interface of the compost at two random locations for the Control and Biochar Treatment. A two-gallon compost sample from the dugout area was obtained for each Control and Biochar treatment, consolidated into buckets, and mixed well.

Six random samples were taken from each Control and Biochar treatment pile during the curing stage and consolidated into their respective bucket.

One-gallon samples were sent in double-zip lock bags to Wallace Labs and Soil Control Laboratories from these samples. The Wallace samples were sent ground, and the Soil Control Laboratory samples were sent in insulated boxes packed with ice packs to preserve the state of the microbiological cultures for pathogen testing.

RESULTS

Question 1: Does adding ten-volume percent biochar (produced from forestry waste using a Carbonator biochar machine) to a green and food waste pile (80:20 by weight) reduce VOC emissions from a CASP composting system?

Figure 4 presents a line plot of the VOC flux rates measured throughout the run.

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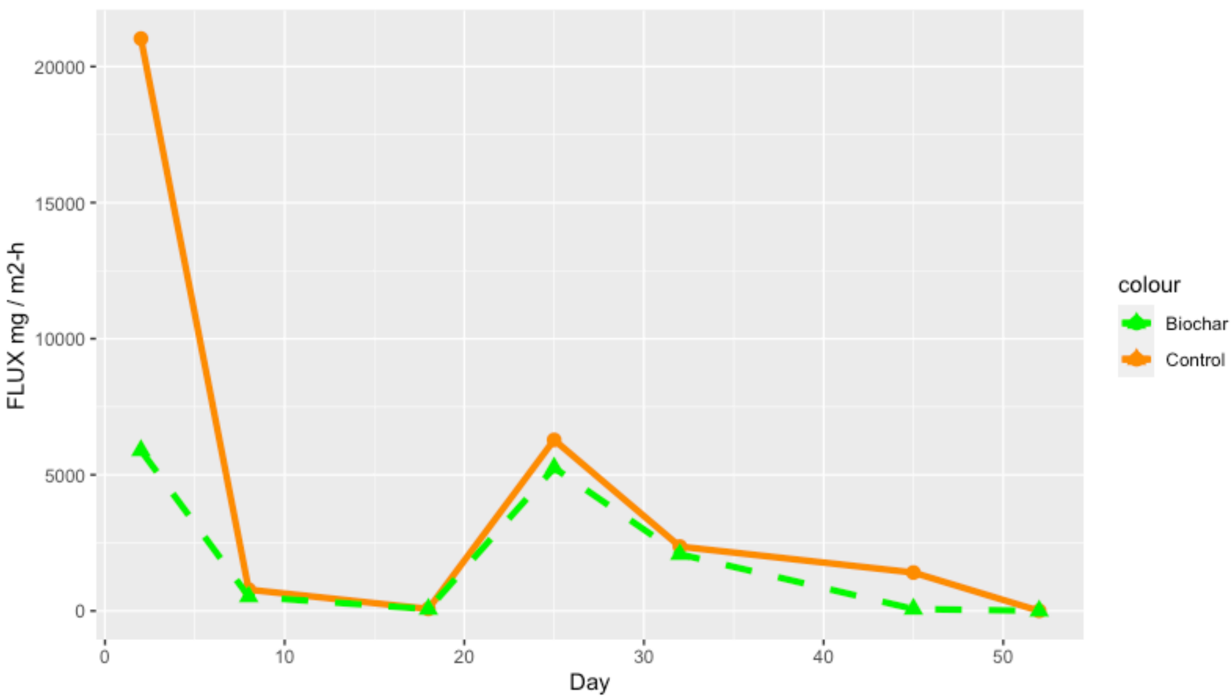
Figure 4: VOC Flux versus Day



This plot shows the average VOC fluxes (rate of emissions per unit area per unit time) for the Control (orange) and the Biochar(green) for each day of testing and taking even more data. Note that the 26 of July and 2nd of August are VOC rates taken during the curing phase after the pile was moved. The team recorded 255 VOC data points over the course of the test. July 26 and August 2 are VOC rates taken during the curing phase after moving the pile.

Table 2 describes the VOC statistics for each day of testing and the composite result. VOC flux rates are reported in milligrams per square meter per hour. The statistics alpha and t-ratio are presented. An alpha of 0.05 and a t-ratio of 2.0 corresponds to a statistical significance of 95 percent. The column Improvement shows the percentage reduction of VOC relative to the Control on that day. The reported Probability was determined from the value of alpha.

Table 2: VOC Fluxes And Statistics Across The Composting Cycle

		VOC Flux mg/m2-h					
Date	**Day**	**Control**	**Biochar**	**alpha**	**t-ratio**	**Improvement**	**Probability**
13-Jun	2	21026	5896	0.004	5.529	72%	99.6%
19-Jun	8	781	527	0.257	1.153	33%	74.3%
29-Jun	18	74	67	0.003	3.195	9%	99.8%

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6-Jul	25	6282	5255	0.263	1.148	16%	73.7%
13-Jul	32	2365	2082	0.216	1.276	12%	78.4%
26-Jul	45	1409	71	0.000	6.066	95%	100.0%
2-Aug	51	0	0		NA	NA	
Composite	**all**	**1964**	**1315**	**0.089**	**1.711**	**33%**	**91.2%**

The impact of the biochar was greatest at the beginning of the run. The result is statistically significant (alpha less than 0.05). On every day of testing, the VOC flux for the Control was higher than the Biochar. The statistics show that some days provided greater than 95% confidence that VOC emissions were reduced.

On average, biochar reduced VOC emissions by 33% (composite)

On every day of testing (seven days), the VOC flux for the Control was higher than the Biochar. If this is random data (biochar having no impact), you would expect at least some days to show a negative effect of biochar. By analogy, in a coin toss, the probability of seven flips, all being heads (or tails), is (1/2) ^7 = 0.78 percent; in other words, the confidence level that biochar reduced VOC is 100-0.78 = 99.2% by this method.

Figure 5 presents a box plot of the VOC flux data taken on day 2, the first day of testing. Each box represents the range where 75% of the data falls. The median of the data is represented as the line in the box, and the whiskers outside of the box show the spread of the data outside of the interquartile range. Box charts for each testing day are shown in the Appendix, which shows graphically that VOC fluxes were lower on each day of testing.

This exceptional and consistent result shows that the biochar reduced VOC emission rates.

Figure 5: VOC Flux Box Plot First Day of Testing

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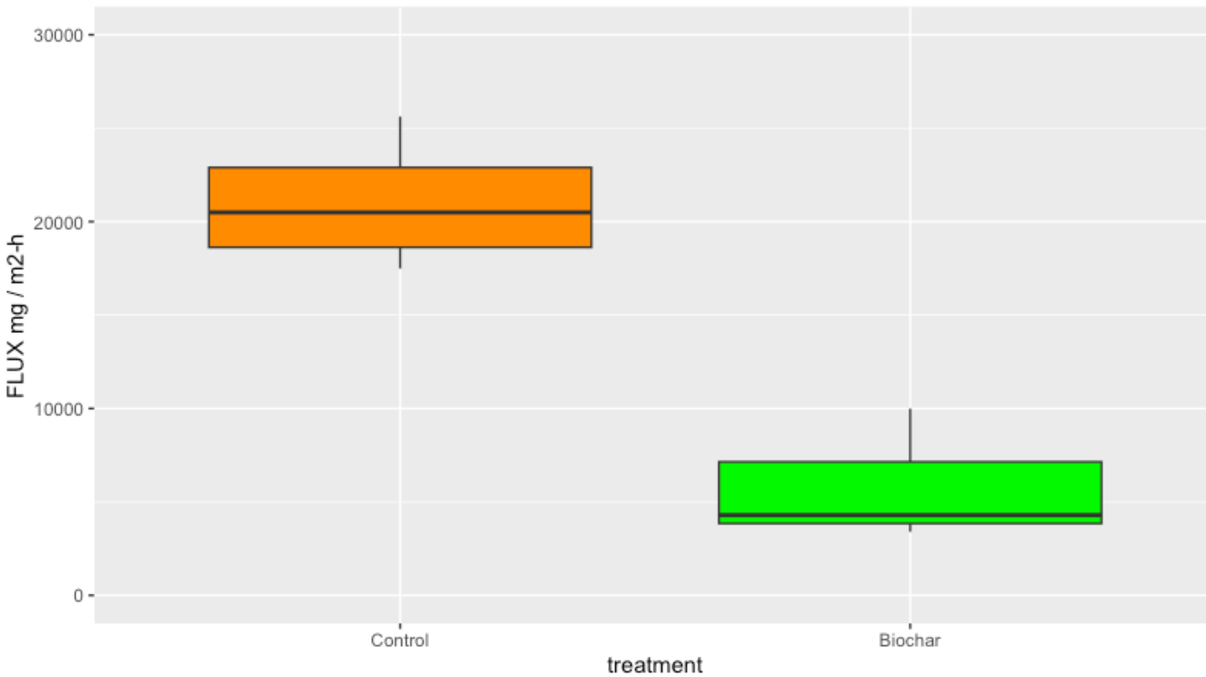

Question 2: Does Biochar reduce the time to maturity as measured by exchangeable ammonium and cucumber emergence bioassay?

Table 3 shows the exchangeable ammonium and cucumber emergence results throughout the compositing cycle.

Table 3: Compost Maturity Over The Course of the Composting Cycle						
	Exchangeable Ammonium, ppm			**Cucumber Emergence**		
Date	**Control**	**Biochar**	**Difference**	**Control**	**Biochar**	**Difference**
19-Jun	87	142	63%	100%	100%	0
29-Jun	86	293	241%	100%	100%	0
6-Jul	91	330	263%	100%	100%	0
17-Jul	970	464	-52%	93%	100%	8%
26-Jul	747	315	-58%	100%	100%	0
2-Aug	263	46	-83%	100%	100%	0

Exchangeable ammonium in the final compost product on August 2nd was 83 percent lower with the biochar treatment than the control. The biochar treatment achieved a much higher level of maturity than the control on July 17th, four weeks into the cycle. Biochar reduced the time to maturity relative to the control, as measured by Exchangeable ammonium.

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The results show no significant impact on the compost maturity with Biochar as measured by cucumber emergence, as all results achieved high levels of cucumber emergence throughout the cycle.

Question 3: Does adding Biochar improve nutrient availability and reduce the finished compost's salinity (ECE and chloride)?

Table 4 shows the total nutrient content of the finished compost, comparing the control to biochar.

Table 4: Total Nutrient Content of Finished Compost			
	Control	**Biochar**	**Difference**
Density, pounds/cy	1004	961	
Moisture, w%	52.5%	55.9%	
Dry Density	477	424	-11%
# per cubic yard			
Nitrogen	6.92	7.28	5%
Phosphorous as P2O5	1.66	2.43	46%
Potassium as K2O	3.98	4.26	7%
Total N+P+K	**12.56**	**13.97**	**11%**
C/N	19.6	18.3	-7%

Despite the biochar-amended compost having a lower overall density (attributed to the low density of the biochar), the Total N+P+K content of the finished product came in at 11 percent higher than the control. Phosphorous was extremely high for the biochar product at 46% enhancement. The C/N ratio of the biochar treatment was lower than the control despite biochar having a much higher carbon content than green and food waste.

Table 5 presents the extractable nutrients of the composts as a percentage of the underlying Total.

Table 5: Extractable Nutrients as a Percentage of the Underlying Total Concentration			
	Control	**Biochar**	**Difference**
Density, pounds/cy	1004	961	-4%
Moisture, w%	52.5%	55.9%	+6%
Dry Density	477	424	-11%
Calcium	30%	20%	-33%

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Magnesium	33%	29%	-11%
Phosphorous	49%	32%	-35%
Potassium	87%	73%	-16%
Boron	47%	34%	-28%
Sodium	64%	62%	-5%

Despite the nutrient enrichment of the compost, the biochar rendered the nutrients in the compost less available. This laboratory analysis indicates that it will take longer for the natural mineralization processes in the soil to release nutrients from the Total pool. In other words, the biochar imparted a nutrient time-release property to the compost. Over the long term, with healthy soil, the entire Total pool is expected to be released into the soil.

Table 6 shows the concentrations of nutrients and salts in the saturated extract for the control and biochar treatments.

Table 6: Nutrient Concentrations in the Soluble Extract of the Finished Compost			
	Control	**Biochar**	**Difference**
pH	7.59	7.93	4%
ECE (salts), dS/m	3.9	3.37	-14%
Calcium (ppm)	80	39	-51%
Magnesium (ppm)	39	17	-56%
Sodium (ppm)	192	185	-4%
Potassium (ppm)	547	520	-5%
Chloride (ppm)	410	418	2%
Nitrate as N (ppm)	11	10	-9%
Phosphorous (ppm)	11	7	-36%
Boron (ppm)	0.61	0.42	-31%

Overall, the Electrical Conductivity of the Saturated Extract Decreased with adding biochar to the feedstock. Lowering ECE in soil reduces plant osmotic (salt) stress, which can improve growth. Different plants have different sensitivities to ECE. Levels of six and above generally cause stress to most plants. Composts exceed levels of six and occur frequently.

Significant reductions in the concentration of calcium and magnesium, phosphorous, and boron in the soluble extract were observed. These reductions mirror the result reported in the extractable nutrient levels. The reduction in concentrations of these elements contributed to the reduction in ECE of the biochar-treated compost.

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Plants generally are sensitive to chloride levels above 800 ppm in the saturated extract. Chloride levels were in the low 400 ppm in both composts, and biochar had minimal impact on chloride concentrations. Plants are also sensitive to boron at levels above one ppm. Biochar reduced boron concentration in the compost by 31%, a property of this material that could be used to remediate soils high in boron.

Nitrate levels in the soluble extract were not impacted by adding biochar. Nitrate is the usable form of nitrogen for plants.

Question 4: Does adding Biochar reduce the C/N ratio of the finished compost, adjusting for carbon addition from Biochar?

Table 7 shows the calculation to determine the equivalent C/N ratio of the biochar compost, subtracting out the fixed carbon and nitrogen contributed from the biochar.

Table 7: C/N Ratio of Biochar-Compost, Subtracting out Biochar Fixed Carbon and Nitrogen

	#	% C	# C	% N	# N	C/N	Reduction
1CY Control-comp	480	28.3%	135.84	1.4%	6.91	19.7	Baseline
1CY Biochar-comp	424	31.4%	133.26	1.7%	7.29	18.3	-7%
- 0.1 CY biochar	10.5	86.6%	9.09	0.6%	0.06	151.9	
Adjusted comp			**124.17**		**7.23**	**17.2**	**-13%**

The C/N ratio impacts the mineralizable nitrogen, and the carbon and nitrogen contributed to the biochar will never become mineralizable. Therefore, the contribution of carbon and nitrogen from the biochar was subtracted to give a ratio that can be compared directly to the Control.

The result shows an adjusted C/N ratio for the biochar compost of 17.2, 13 percent below the Control compost. Therefore, adding biochar reduced the C/N, increasing the mineralizable nitrogen content of the finished compost and reducing the need for chemical nitrogen fertilizer relative to Control.

Question 5: Does the use of biochar impact pathogen reduction?

Table 8 presents the pathogen testing results for each sampling week.

Table 8: Pathogen Testing Results

	Salmonella, MPN/4g		Fecal Coliforms, MPN/g	
Date	**Control**	**Biochar**	**Control**	**Biochar**

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19-Jun	< 3	< 3	**3300**	**1400**
29-Jun	< 3	< 3	**140**	**1100**
6-Jul	< 3	< 3	**560**	**480**
17-Jul	< 3	< 3	**61**	**2200**
17-Jul	< 3	< 3	**240**	**2200**
26-Jul	< 3	< 3	**2000**	**2400**
2-Aug	< 3	< 3	**2800**	**2800**

Both the Control and Biochar Treatments achieved the required elimination of Salmonella. Neither the Control nor Biochar Treatments achieved satisfactory Fecal Coliform reductions. It should be noted that these samples were taken upstream of the regulatory test point for pathogens; therefore, the result does not represent the condition of the salable compost product.

Question 6: Does mixing Biochar in green waste produce a greater exotherm relative to Control?

Figure 6: Pile Temperature Profiles

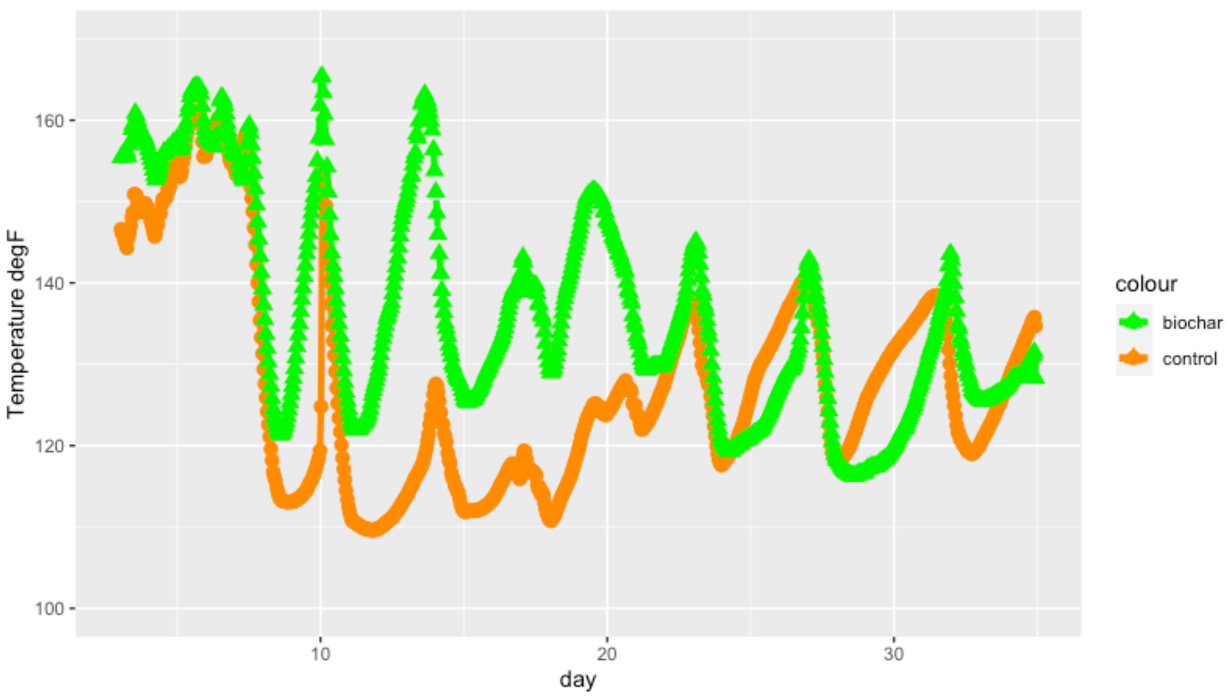

Figure 6 shows the temperature profile for the Control and Biochar treatments during the thermophilic state of composting.

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Adding biochar contributed to significant exothermic energy release relative to Control, resulting in higher temperatures throughout the cycle. The mean temperature for the control was 128 deg F, and the biochar was 136 deg F. Comparing the means, the Alpha was less than 10-4, and the t-statistic was calculated-19, indicating the means were different to consider statistical significance.

This exotherm is attributed to increased microbiological carbon dioxide respiration associated with reducing the carbon content of the compost pile, thereby reducing the C/N ratio and concentrating nutrients in the final product.

CONCLUSIONS

The results of this study indicate that with high probability, adding biochar to the base feedstock reduced VOC emissions from the CASP system.

Curing was also accelerated using biochar, reducing the time for ammonium to be below 50 ppm by one week and near-zero VOC emissions by two weeks.

The effect of adding biochar to the feedstock was to concentrate the Total nutrients in the final product. One explanation for this concentration effect is the significant exotherm of the biochar-enabled process, causing additional carbon to be removed from the compost as CO_2 from microbial respiration.

The concentration effect was particularly significant in the case of phosphorus, with a 46% enhancement. Phosphorus is an essential element for all living organisms and is a critical component of fertilizers, making it crucial for modern agriculture. There are fears that we are running out of the nutrient and are reaching “peak Phosphorous” production, analogous to peak Oil, reducing our ability to feed people, so this finding could be a particularly valuable discovery if further developed.

Adding biochar reduced the C/N ratio of the finished compost at a rate of 13% relative to control, adjusting for the fixed carbon in the biochar to a level of 17. A compost with a C/N of 17 would have about 10% mineralizable nitrogen that can be released to the soil in a year timeframe. Lower C/N ratios translate to higher levels of mineralizable nitrogen. Conventional organic fertilizers such as Dry Meal, Blood Meal, and Guano have C/N ratios in the range of 4, with 70% of the nitrogen mineralizable. Organic fertilizers can sell for $500-1000 per ton, and chemical nitrogen fertilizer sells for over $500 per ton, compared to compost, which sells for $25 per ton at the retail level. Therefore, there is a significant incentive to reduce the C/N level of finished compost because such a product could economically displace organic fertilizers and chemical nitrogen at scale.

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For nutrients other than nitrogen, adding biochar to the feedstock imparted a time-release dimension to the plant nutrients. Because of this effect, the salinity in the Saturated Extract of the final compost was reduced. Although the composts tested in this program had low salinity levels, many composts are challenged with high salinity, causing stunted plant growth. The addition of biochar could mitigate compost salinity challenges. Co-composted biochar could also be used to remediate sodic-saline soils, addressing problems like the large-scale land degradation in the Central Valley from salinity encroachment.

Only one composting run was completed in this study. Therefore, we did not qualify the results across varying and non-uniform feedstock sources, incomplete mixing, variable and dynamic aeration, and non-uniform hydration, characteristic of commercial-scale composting operations.

RECOMMENDED AREAS FOR FUTURE RESEARCH

Sized Biochar: The benefits of co-composting in this study were likely muted due to the predominately large size of the biochar. 84.9 percent of this material is sized above four millimeters, reducing the surface area available for chemistry relative to its mass. Therefore, the benefits of co-composting are expected to increase by reducing the size to 1-4 millimeters through screening and/or additional crushing. Significantly reducing the C/N ratio of the final compost would be a breakthrough because the composting process could compete economically with chemical nitrogen fertilizer production.

Replicated Experiments: Qualifying the results across the variabilities of commercial operations, such as feedstock variability, and improving the mixing process to eliminate no-uniformities in the feedstock mix. Drone monitoring of yields to validate the nutrient concentration effect enrichment effect magnitude.

Saline-Sodic Soil Remediation: Nursery trials, followed by Agriculture field tests, demonstrating the ability of co-composted products to remediate degraded land in places like the Central Valley, California.

Outreach: Presentation of learnings at prospective customer industry events.

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Learn more about Earth Foundries grant-funded Biochar Market Development projects at: https://www.earthfoundriesinc.com/biochar-market-development/,
and/or contact Roger Smullen with Earth Foundries: roger.smullen@earthfoundriesinc.com

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APPENDIX: Schedule

	Bunker - Thermophilic & Mesophilic						Windrow - Cure	
	Day 1 6/12/23	Day 2 6/13/23	Day 8 6/19/23	Day 18 6/29/23	Day 25 7/6/23	Day 36 7/17/23	Day 45 7/26/23	Day 51 8/2/23
Operations								
Mix Biochar, Form Piles	X							
Setup VOC Equipment Test Run	X							
Training		X						
Control								
Flux Chamber VOC		3, 1-day	3, 1-day	3, 1-day	3, 1-day	3, 1-day	3, 1-day	3, 1-day
Wallace Complete		X						
Control Labs Compost		X	X		X			
Biochar								
Flux Chamber VOC		3, 1-day	3, 1-day	3, 1-day	3, 1-day	3, 1-day	3, 1-day	3, 1-day
Wallace Complete		X						
Control Labs Compost		X	X		X			

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APPENDIX: VOC Boxplots for Each Day of Testing (day 51 both treatments were zero)

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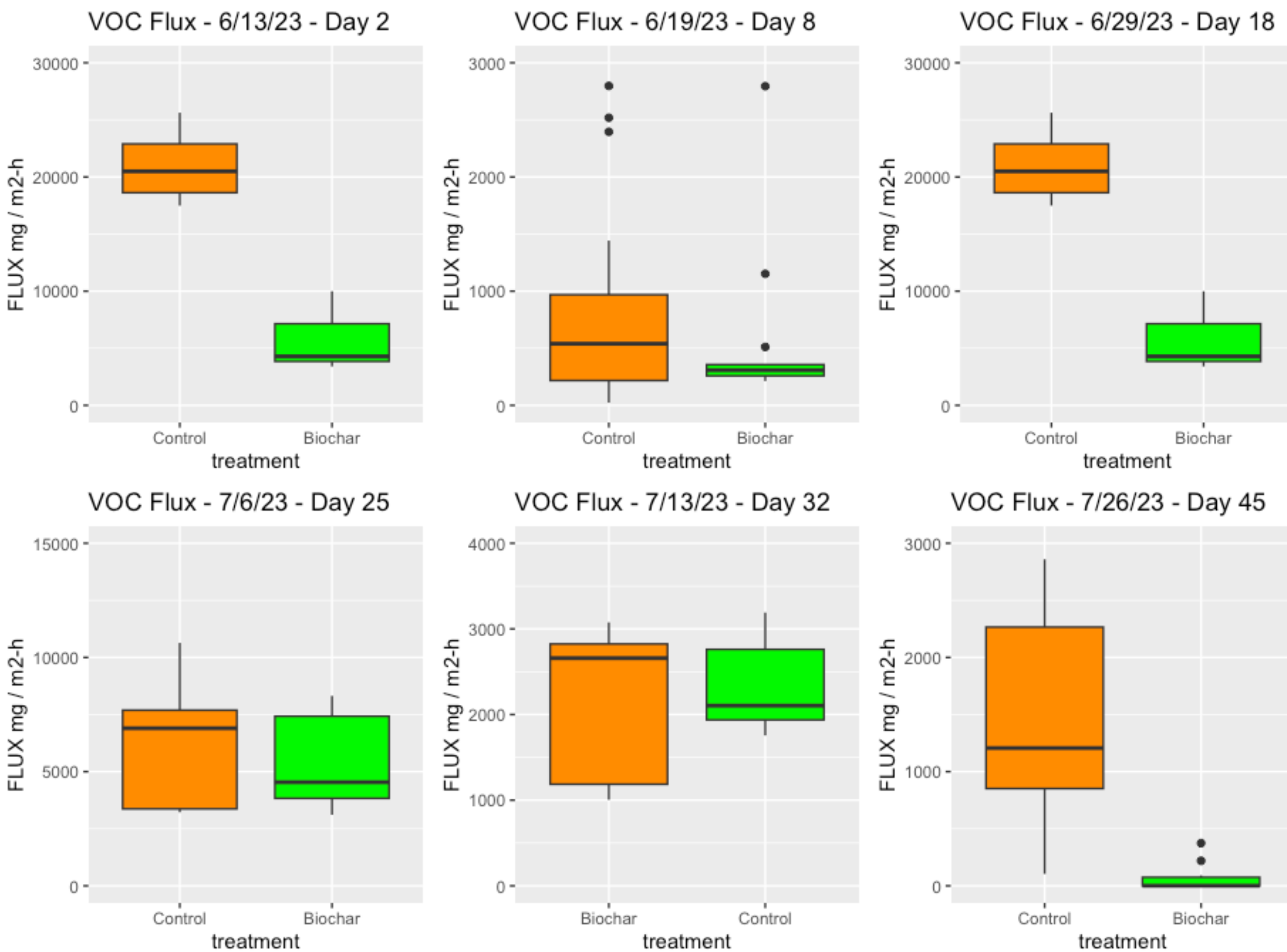

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