**Details of Anaerobic Digester Construction, Operation and Chemistry**

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**Purpose**

The document serves as supplemental material for the manuscript “Biogas Digestate as a Renewable Fertilizer: Effects of Digestate Application on Crop Growth and Nutrient Composition”. The goal of this document is to detail the process of constructing and maintaining the anaerobic digesters used in the experiment to allow interested readers access to this information.

**Introduction**

Anaerobic digestion (AD) is a process by which organic matter is decomposed into a nutrient-rich digestate (effluent slurry) and an energy rich gas (CH4, CO2). AD is a multiple-stage process that includes hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Venkiteshwaran et al., 2015). In this process, organic waste is hydrolyzed into basal components, converted from sugar into acetic acid before being digested into carbon dioxide, methane and other trace gases by an array of microbes including methanogenic archaea (Liu & Whitman, 2008). AD feedstocks commonly used on farms (livestock manure, food waste, yard waste) are rich in NPK and various trace elements, including Mg, Ca, S. These nutrients pass through the digester in the liquid phase, providing components of a dilute fertilizer in system effluent, referred to as digestate (Nkoa, 2014). Micronutrient presence is necessary to optimize digester activity (Demirel & Scherer, 2011). A healthy methanogenic community is vital in producing biogas with a high methane content (>60%). Addition of fresh ruminant livestock manure to anaerobic systems is a simple way of providing a robust microbial base. Anaerobic systems typically operate at a slightly basic pH (~8.0) due to inherent microbe buffer systems; however, neutral pH conditions reduce ammonia inhibition resulting in higher percentage CH4 biogas production at pH 7.0 (House, 2010). Digester operations peak at pH values between 6.9 and 7.0 and temperatures ranging from 29 ℃-44 ℃, depending on the organic matter feedstock source (Cioabla et al., 2012, Liu, C. et al., 2018).

**Materials & Methods**

**Anaerobic Digester Construction**

The digestate used in this study’s compost and greenhouse bioassays was generated from plug-flow digesters located on the Dickinson College Organic Farm in Carlisle, PA (lat 40°08’N, long 77°08’W). Two digesters were constructed from 45 mil reinforced EPDM roofing membrane and glued into a 1 m diameter, 7 m long tube shape. Custom-fabricated polypropylene caps, fitted with valved ports for slurry, gas, and supernatant inlet and outlet piping were clamped at each end of the digesters using waterproof caulking to create a hermetic seal. Batch loading of influent slurry occurred by gravity feed resulting in an equivalent volume of effluent forced out in the process. A high flow pump on the supernatant line was used to recirculate fluid from the effluent end after each batch loading for microbial seeding and to provide physical mixing. A schematic of the digesters can be found in Figure 1. Digesters were housed in a 0.5 m trench lined with 5 cm insulation board, inside a small greenhouse to increase digester operating temperatures. This study was conducted in summer months when digester temperatures typically stabilize around 35 C (data unavailable).

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**Figure 1:** A cross-section schematic of the anaerobic digester utilized in the study.

Digestion feedstocks for the study period was predominantly ground cafeteria food waste as described in the main article. Fresh manure from beef cattle was used as microbial seed at project startup. Biogas was used on site for cooking and heating fuel. Digestate generated during routine operation that was not utilized for the bioassays was applied to compost piles and fields of cover-crops for nutrient fortification.

**Metrics for Analysis of Digester Health**

To monitor digester health, alkalinity, pH and approximate gas composition were recorded 2 times/week and total gas production was recorded daily. Alkalinity was tested by titrating 50 mL of recirculated supernatant with 1 M HCl in water. HCl was added until the digestate pH was initially reduced to 5.75, and finally to 4.0, with the volume of added HCl being recorded for each reduction. Volatile fatty acids (VA) and bicarbonate alkalinity (Alk), both in mg CaCO­3/L, were calculated by the equations:

$VA=\frac{Titrant Vol from 5.75 to 4.0 pH \left(mL\right) x Titrant Conc \left(N\right) x Digester vol\left(L\right) x Feed Weight (kg) }{Volume Sample(mL)}$.

$Alk=\frac{Titrant Vol to 5.75 pH \left(mL\right) x Titrant Conc. titrant\left(N\right) x Digester vol\left(L\right) x Feed Weight (kg) }{Volume Sample(mL)}$.

VA/Alk was calculated by dividing volatile fatty acids by bicarbonate alkalinity. Healthy values range from 0.1 to 0.35 (Schnaars, 2012). Digestate pH was measured by an Accumet XL20 pH/conductivity Meter, calibrated at pH 4.0, 7.0 and 10.0. Approximate gas composition (% CH4 and CO2) was determined by filling a 30-mL glass syringe with 25 mL of biogas and 5 mL of saturated KOH solution, inverting and observing the change in volume of gas as the CO2 was removed from the headspace via interactions with KOH (House, 2010). The percent volume change is correlated with the percent CO2 vs. CH4. Typical methane composition from anaerobic digesters ranges from 60% to 70% CH4 (Schnaars, 2012).

**Results & Discussion**

During the study period, biogas composition (by simple bench test) ranged from 60-70% CH4 and 30-40% CO2, which is in line with expected values (Figure 2). Biogas was pumped through a simple scrubber (Schedule 40 PVC pipe, 10 cm diameter, 1 m long, packed with Iron Sponge – an iron oxide product) to remove H2S. VA/Alk values for the recirculated biogas supernatant ranged from 0.65 to 0.1, with most values falling between 0.45 and 0.2 (Figure 1). Higher VA/Alk values were correlated with increased organic matter loading. As feeding amounts decreased from 3 times/week to 2 times/week between 10 and 20 days after operations began, the VA/Alk dropped into the healthy range. Effluent for greenhouse bioassay feeding dilutions was taken from the system during this time frame.

**%CH4**

**VA/Alk**

**VA/Alk**

**Figure 2:** Biogas %CH4 and Digestate VA/Alkduring digestor monitoring period. %CH4 and VA/Alk values reached ideal ranges at approximately day 20 due to proper organic loading.

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