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BIOENERGY RESEARCH INITIATIVE
NC DEPT OF AGRICULTURE & CONSUMER SERVICES

Thermophilic Anaerobic Co-Digestion of Swine Wastewater and Lemnaceae for Biogas Production

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Abstract

Lemnaceae, commonly referred to as duckweed, has shown great potential as a next generation biomass feedstock for anaerobic digestion that is decoupled from arable land use. Lemnaceae plants grow incredibly fast, can be harvested continuously, and have nutrient uptake capabilities, making them an ideal candidate for a joint wastewater treatment and bioenergy production system. For the first time, we developed a continuous system that treats swine wastewater via Lemnaceae production with subsequent conversion to biogas via thermophilic anaerobic digestion.

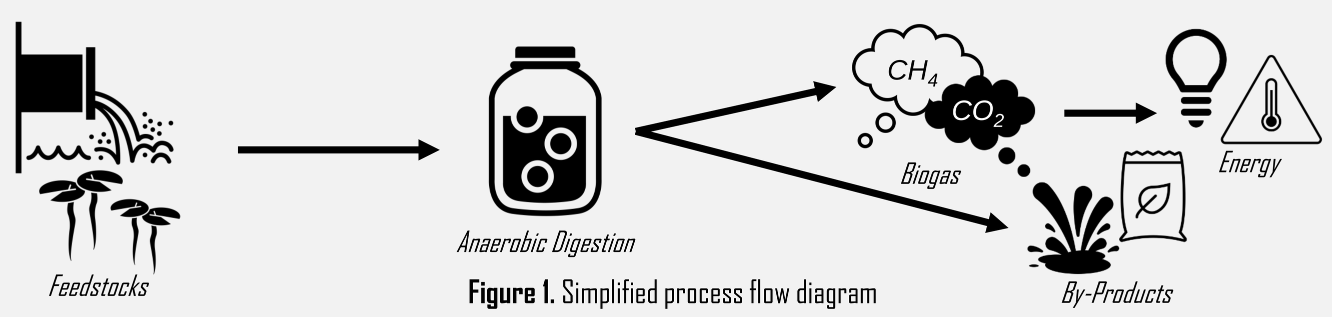

Figure 1. Simplified process flow diagram

This project aimed to elucidate the effects of several bioprocess parameters on the digestion of three Lemnaceae species, with a particular focus on the effect organic loading rate had on the biogas production rate and digestate composition.

Research Questions

1. Is it feasible to convert **Lemnaceae into biogas** in a **thermophilic anaerobic digester**?
2. What is the **optimal organic loading rate** for Lemnaceae and swine wastewater co-digestion for biogas production?
3. What is the **ultimate methane production** (BMP) from Lemnaceae biomass?
4. What **kinetic models** and parameters fit the experimental BMP data?

Results & Discussion

Continuous Digestion: Daily biogas production increased significantly ($p < 0.05$) upon addition of Lemnaceae biomass and increased organic loading rate (OLR). **Methane content (% vol.) and COD reduction efficiency decreased** following the addition of Lemna. **The specific methane production rate (SMP) significantly increased with increasing OLR** and was significantly different between Lemna types (Figure 4). **Maximum SMP of 0.362 m^3 CH_4 kg^{-1} COD consumed was observed from the Spirodela – Culbreth reactor at the highest OLR. MAYBE ADD A SENTENCE TO MAKE THIS LOOK BETTER?**

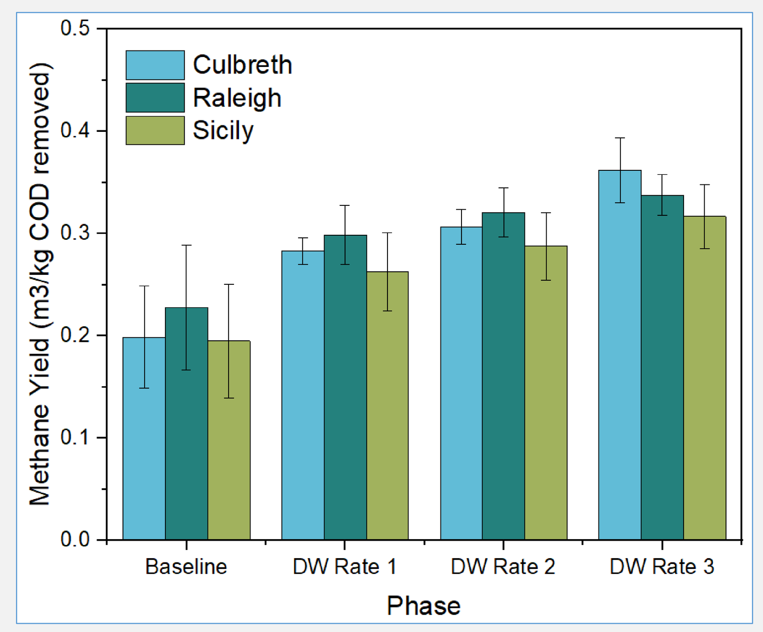

Figure 4. Daily biogas measured from three continuous digesters throughout baseline (swine wastewater) and duckweed (DW) loading rates described in Table 1.

Batch Digestion: The biomethane potential (**BMP**) of the three Lemna types were **205, 217, and 262 mL CH_4 g^{-1} VS fed** for the Culbreth, Raleigh, and Sicily Lemna types, respectively (Figure 5). Based on **kinetic model fit criteria** (Table 2), the first order and transference kinetic models had the best fits to the experimental data. The **key parameters** determined by these two models are displayed in Table 3.

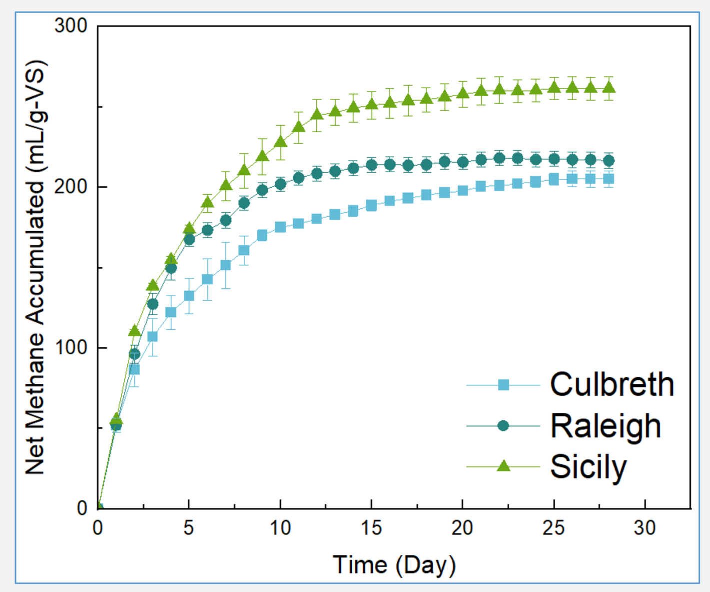

Figure 5. Net methane volume accumulated throughout 28-day batch digestion

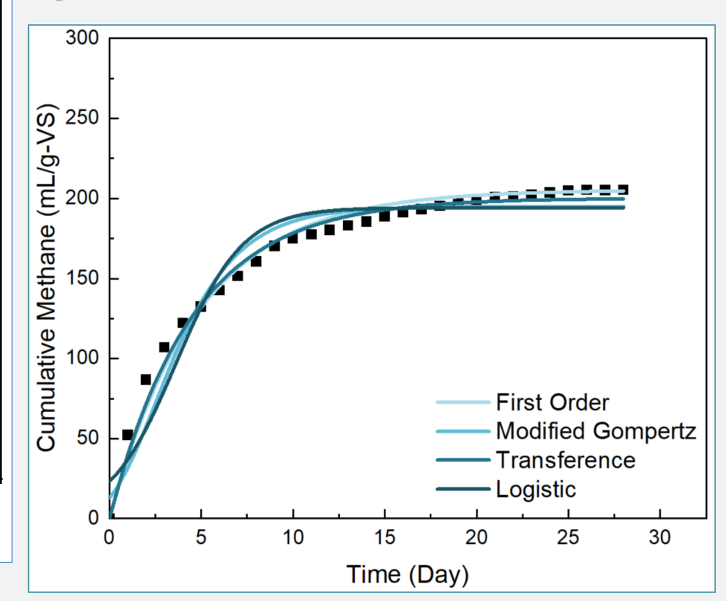

Figure 6. Kinetic model curve fitting for Raleigh Lemna.

Table 2. Model fit criteria used to select the kinetic models with the best fits to the batch digestion experimental data.

Model	Statistical Indicator	Duckweed Type			Model	Statistical Indicator	Duckweed Type		
		Culbreth	Raleigh	Sicily			Culbreth	Raleigh	Sicily
First Order	Adjusted R^2	0.993	0.999	0.995	Transference	Adjusted R^2	0.986	0.986	0.995
	RMSE	3.270	1.45	4.654		RMSE	5.878	5.573	4.636
	AIC_c	93.75	25.21	92.63		AIC_c	102.8	104.7	89.04
	BIC	94.97	27.48	94.90		BIC	104.0	109.3	93.62
Modified Gompertz	Adjusted R^2	0.946	0.977	0.966	Logistic	Adjusted R^2	0.965	0.997	0.949
	RMSE	11.73	5.82	12.29		RMSE	7.51	2.54	15.07
	AIC_c	142.9	145.6	147.9		AIC_c	153.0	158.8	157.4
	BIC	144.1	147.9	150.2		BIC	154.2	163.4	162.0

Table 3. Kinetic parameters determined from the first order and transference kinetic models.

Model	Parameter		Unit	Duckweed Type		
				Culbreth	Raleigh	Sicily
First Order	Ultimate Methane	M_u	mL CH_4 g^{-1} VS	204.7	216.6	261.1
	Rate Constant	k	day^{-1}	0.205	0.285	0.222
Transference	Ultimate Methane	M_u	mL CH_4 g^{-1} VS	200.1	216.4	260.1
	Max Methane Production Rate	R_m	mL CH_4 g^{-1} VS day^{-1}	44.33	62.59	58.79
	Lag Time	λ	day	0	0	0

Methods

Three Lemnaceae types (Figure 2) were selected from a previous study based on growth rates on swine wastewater and local abundance. They were grown on diluted swine wastewater, harvested weekly, air-dried, and milled prior to digestion

Figure 2. Lemnaceae selected for anaerobic co-digestion

For continuous digestion, three continuously stirred tank reactors were inoculated with mesophilic anaerobic sludge, transitioned to thermophilic operating conditions (50 °C) and operated at four loading rates with a 10-day HRT (Table 1). Biogas production was monitored daily and biogas and digestate composition was analyzed weekly.

Table 1. Co-digestion organic loading rates for 125- day continuous digestion experiment

Loading Rate	Feedstock	Total Solids in Feed (%)	COD (mg/L digester/day)
Baseline	SWW	0.3	1,000
DW Loading Rate 1	SWW and DW	1.3	2,000
DW Loading Rate 2	SWW and DW	2.3	3,000
DW Loading Rate 3	SWW and DW	4.3	4,500

Batch digestion experiments were conducted to perform a biomethane potential test (BMP) and kinetic modeling (Figure 3). Reactors were prepared using acclimated inoculum from the continuous digesters and the three Lemnaceae types and a positive control (corn starch) with 20 g VS/L at 1:1 substrate : inoculum. The reactors were kept at 50 °C and allowed to run until biogas cessation. Biogas composition was monitored via gas chromatography.

Kinetic modeling of the batch digestion data was done using the following four models:

First Order

$$M(t) = \boldsymbol{M_u} \times (1 - exp(-\boldsymbol{k}t)$$

Modified Gompertz

$$M(t) = \boldsymbol{M_u} \times \exp\left(-exp\left[\frac{\boldsymbol{R_m} \times e}{\boldsymbol{M_u}} \times (\boldsymbol{\lambda} - t) + 1\right]\right)$$

Transference

$$M(t) = \boldsymbol{M_u}\left(1 - \exp\left(-\frac{\boldsymbol{R_m}(t-\boldsymbol{\lambda})}{\boldsymbol{M_u}}\right)\right)$$

Logistic Function

$$M(t) = \boldsymbol{M_u}\left(1 + \exp\left(\frac{4\boldsymbol{R_m}}{\boldsymbol{M_u}} \times (t - \boldsymbol{\lambda}) + 2\right)\right)^{-1}$$

Where $\boldsymbol{M_u}$ is ultimate methane, $\boldsymbol{k}$ is the first order rate constant, $\boldsymbol{R_m}$ is the maximum methane production rate, and $\boldsymbol{\lambda}$ is lag time.

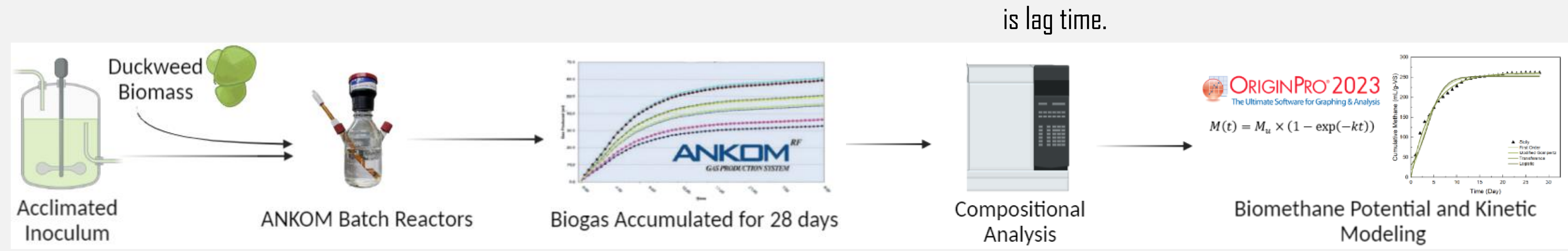

Figure 3. Batch digestion experiment outline for BMP and Kinetic modeling

Conclusions

- Lemnaceae is a viable feedstock for thermophilic anaerobic digestion
- Addition of Lemna biomass increased SMP
- Highest SMP from Spirodela – Culbreth Lemna type at highest OLR
  - 0.362 m^3 CH_4 kg^{-1} COD consumed
- BMP of Lemna types 205 – 262 mL CH_4 g^{-1} VS fed
- First order and transference kinetic models showed best fits
  - k = 0.205 – 0.285 day^{-1}, adequate degradation rates
  - Rm = 44 – 63, 2.5 times higher than reviewed mesophilic systems

Next steps include a metagenomic study of continuous digesters.

Acknowledgements

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