A Closed-Loop Case Study of Food Waste Management in Singapore

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Acknowledgement

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Translating E2S2-CREATE Research to ECLFV

Closing The Food Waste Loop Through Onsite Anaerobic Digestion Eco-System

General food waste

1 Food waste sorting system

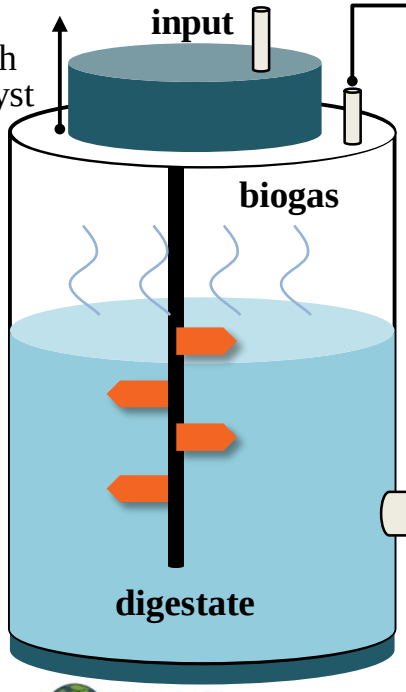
2 Test-bedding of solar-driven thermophilic food waste anaerobic digestion systems in Singapore and China

East coast food village, Singapore

Shanghai, China

3 Odor removal system with nano-catalyst

4 Prediction of anaerobic digestion performance using machine learning



Electricity generator

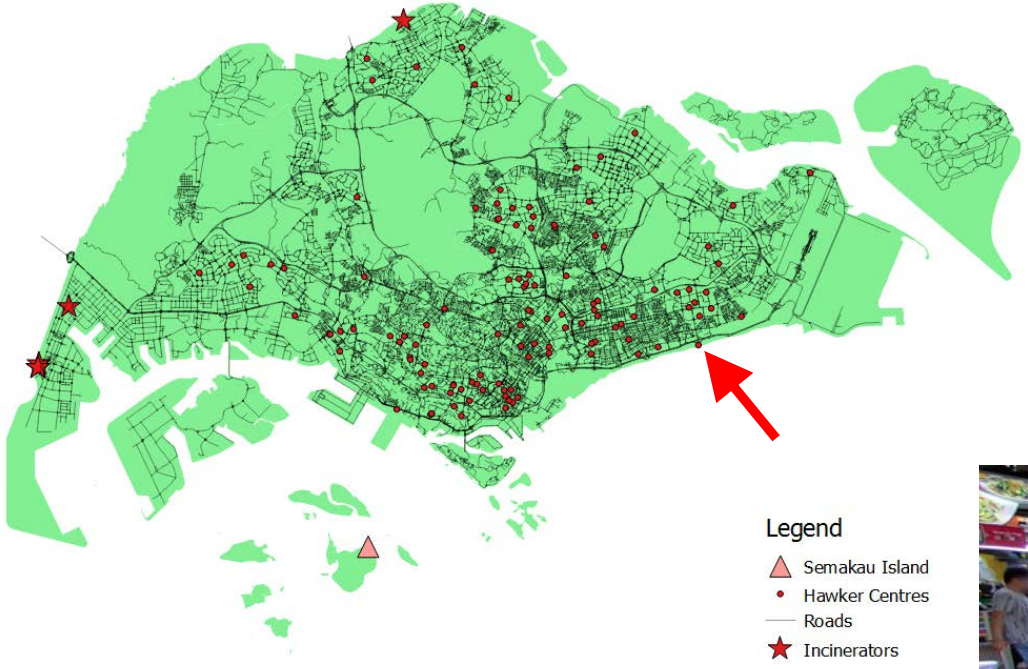
5 The electricity generated from biogas is used by the East coast food village

6 Digestate as fertilizer for the cultivation of the leafy vegetable, xiao bai cai (Brassica rapa)

digestate

Case Study on ECLFV

- Food waste generated at ECLFV: Range from 150kg/day on weekdays, and up to 300kg/day on weekends



Project Scope

Objective: To examine the feasibility (e.g. technical, economic and social) of using on-site Anaerobic Digestion (AD) system to treat food waste for energy and resource recovery.

Main R&D tasks:

(1) Demonstration of a novel customised AD system for on-site food waste recycling;

(2) Behaviour Intervention measures to influence positive behavioural changes among stallholders, patrons and cleaners;

(3) Life cycle assessment (LCA) and cost-benefit analysis (CBA)

Source-segregated food waste from ECLFV

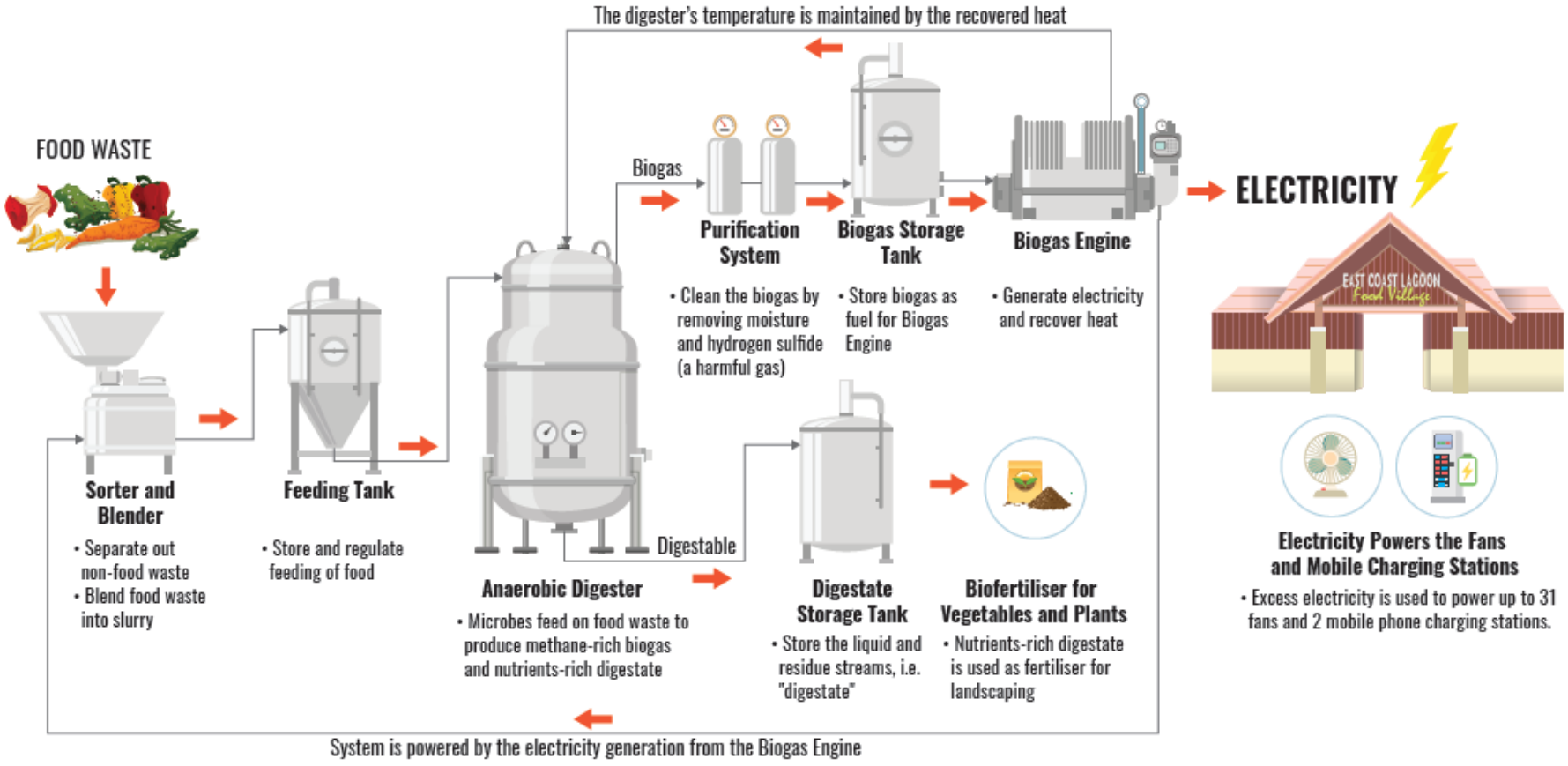
On-site Containerised AD system

Energy Recovery (Electricity) Power up to 31 wall fans

Resource Recovery (Liquid and solid fertilisers) for landscape application at a park

ECLFV AD System Process Flow

- Proposed anaerobic digestion system



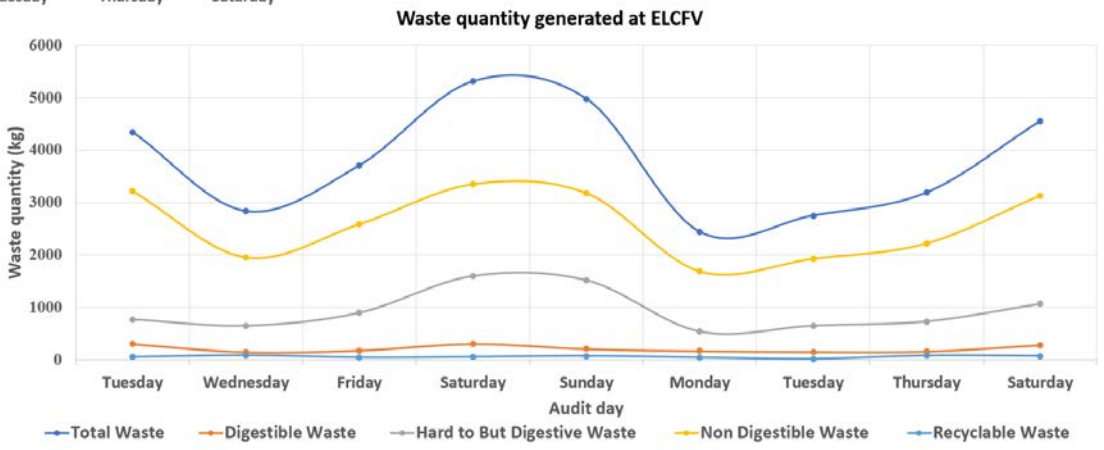
ECLFV Food Waste Audit Findings

- Food waste audit: to customize the system size for ECLFV

1) Anaerobic digester fluctuated loading: the digestible waste generated on weekend days was higher as compared to weekdays;

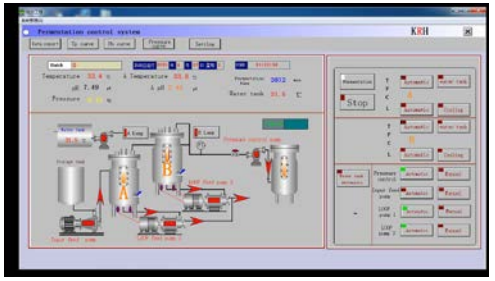
2) An average of 150 kg digestible waste during weekdays and can go up to 300 kg on weekend days

3) The percentage of the digestible waste present in the total waste is around 3.5-7%



Deployment of AD System On-Site

- Customized anaerobic digestion system for ECLFV



Key Components of Customized AD System

- Customized anaerobic digestion system for ECLFV
  - ✓ Two identical digesters (each working volume 3-3.5 m^3)
  - ✓ A sorter and blender system to sort out contaminants
  - ✓ Pressurized biogas storage tank (up to 8bar)
  - ✓ Biogas engine (8.5kw): biogas to electricity
  - ✓ The digestate into fertilizer for landscaping.

Food waste loading system

Food waste sorting system

Overview of the system

Central control panel

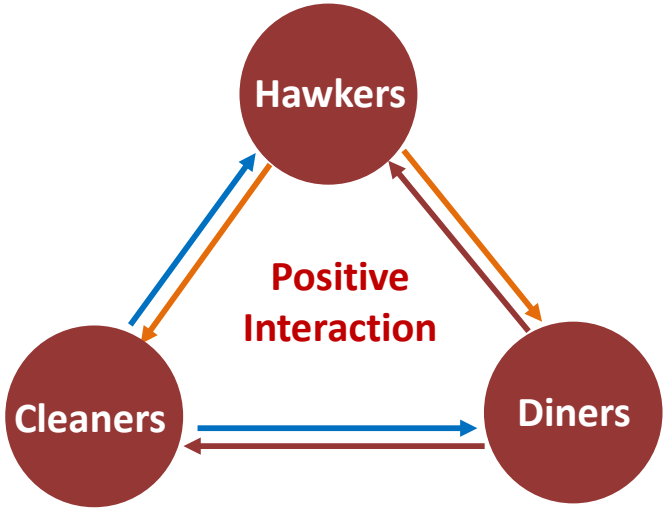
Two main digester

Biogas storage and conversion

Incorporated Human Behavioural Interventions

- Novel four-stage intervention to maximise segregation and recycling of food waste.
  - All stakeholders: stall holders, cleaners, and diners to play their part.
  - **Stage 1**: Information & Education
  - **Stage 2**: Financial Incentives for Stall holders
  - **Stage 3**: Psychological Methods (e.g. tapping on Singaporeans' identity as environmentalists)
  - **Stage 4**: Cross-group Interaction (e.g., food waste segregation efforts of the stall holders, cleaners and diners should be made known to encourage each other)

Publicity Materials



Cross-group Interaction

Supporting Infrastructure

Publicity Posters

Mobile Charging Stations

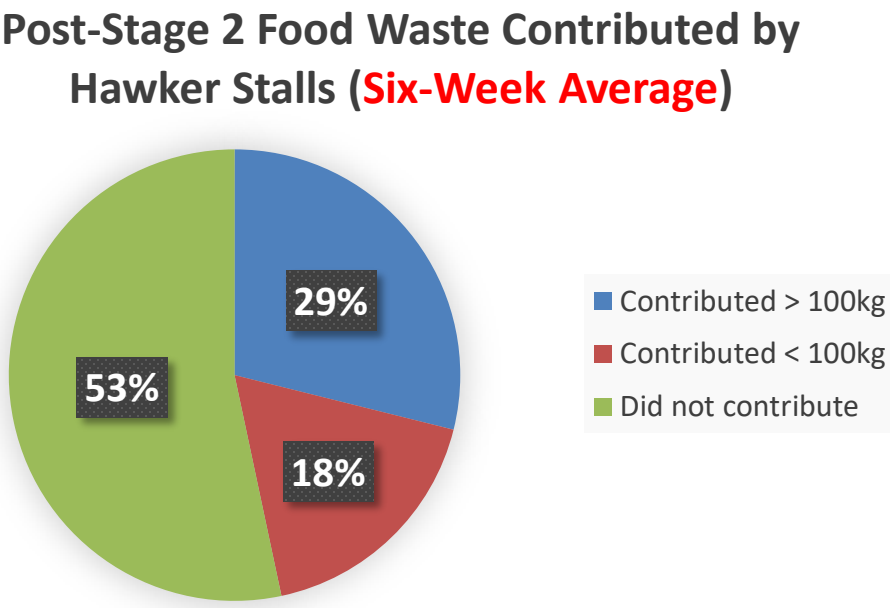
Televisions

Smart Bins

Wall-Mounted Fans

General Results & Findings

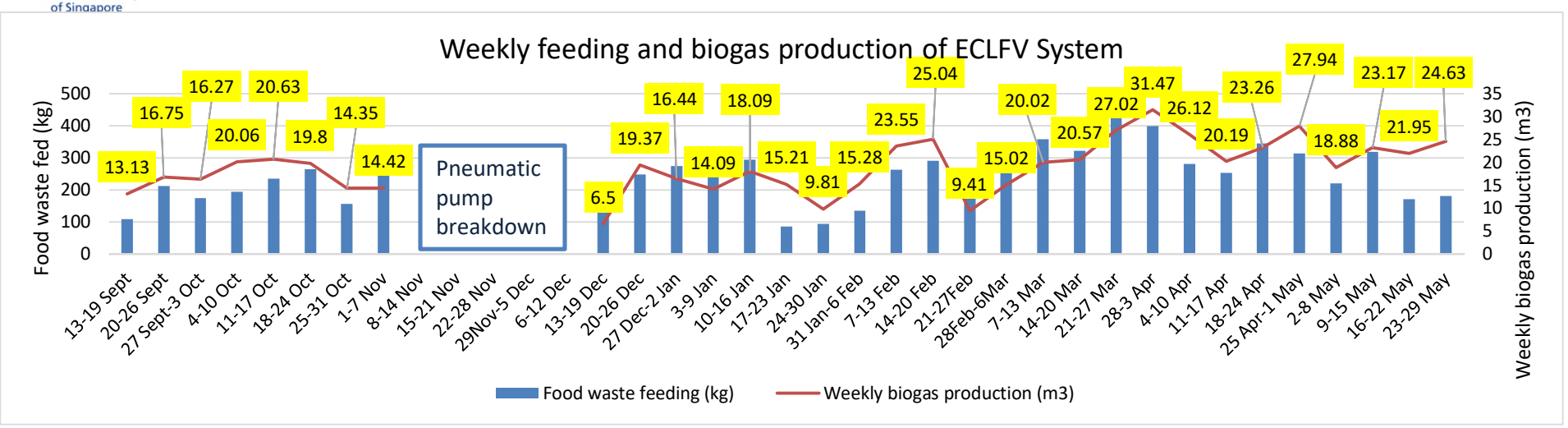
- Since Stage 1, cleaners have segregated 2010kg of food waste (an average of 17.5kg food waste/day).
- Six-week average for hawkers' food waste contributions more than doubled after Stage 2 was implemented (from 823kg to 1862kg).
  - No. of participating stalls increased by 30% (from 16 to 21 stalls).
- Broader noticeable changes in hawkers' psychology:
  - Pre-intervention: 85% of hawkers unaware and unwilling to participate in food waste initiatives.
  - Stage 3: As part of the intervention, 70% of hawkers participated to be interviewed on their efforts in food waste recycling and challenges.

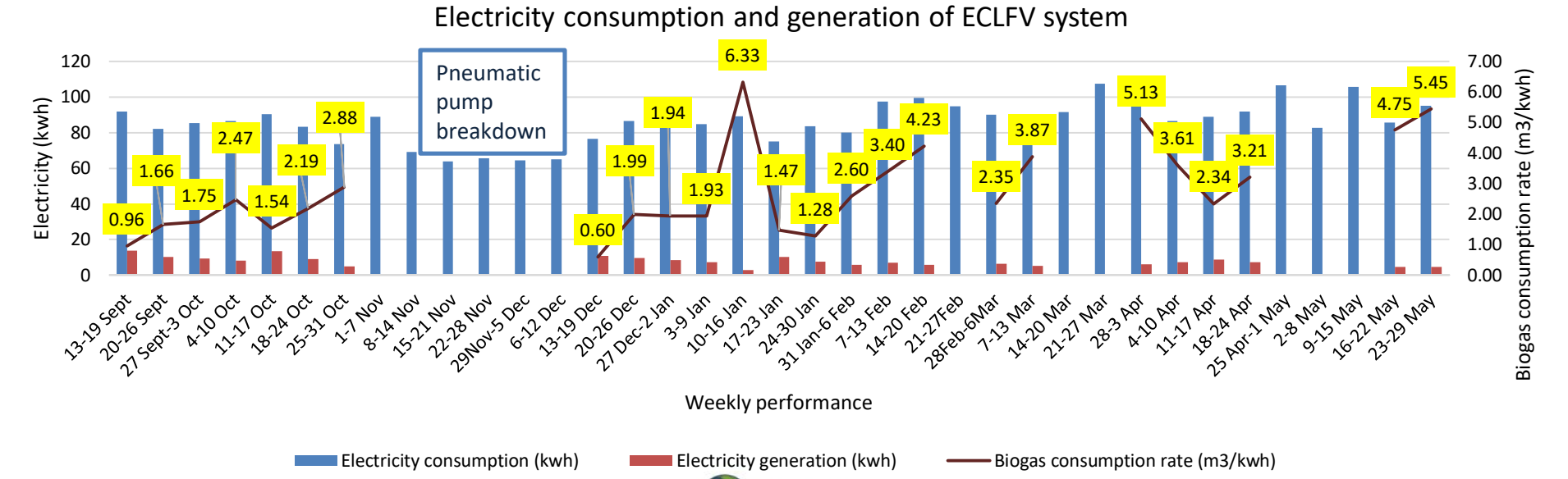


Current Status

Parameter	Details
Food waste fed to AD system	~50-100kg/d, amount progressively increased to designed capacity
Behavioural Intervention	Stage 4: Cross-group interaction currently underway
Digestate study	Testing on ornamental plants to commence

Current Status



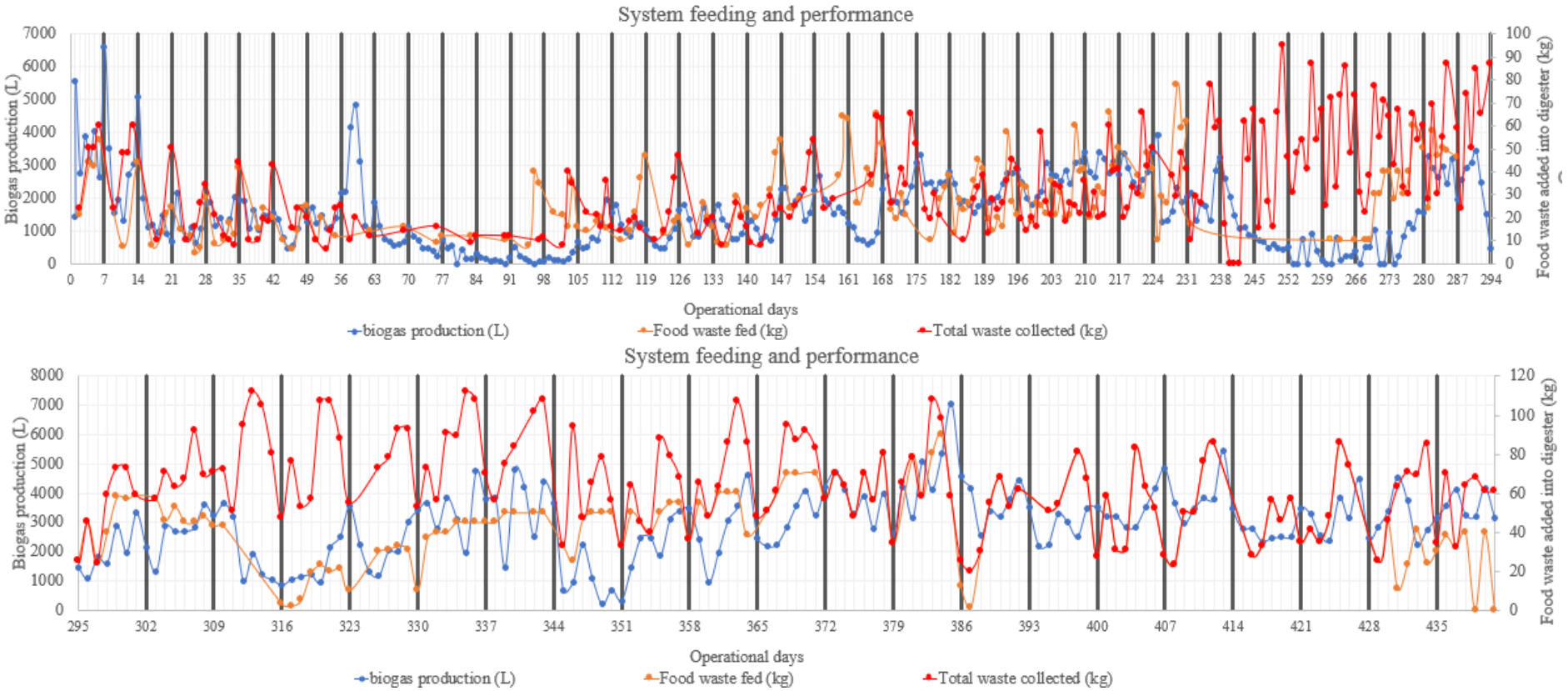


Food Waste Characteristics

- Two main different digestible waste at ECLFV: table waste from diner & vegetable waste from hawker

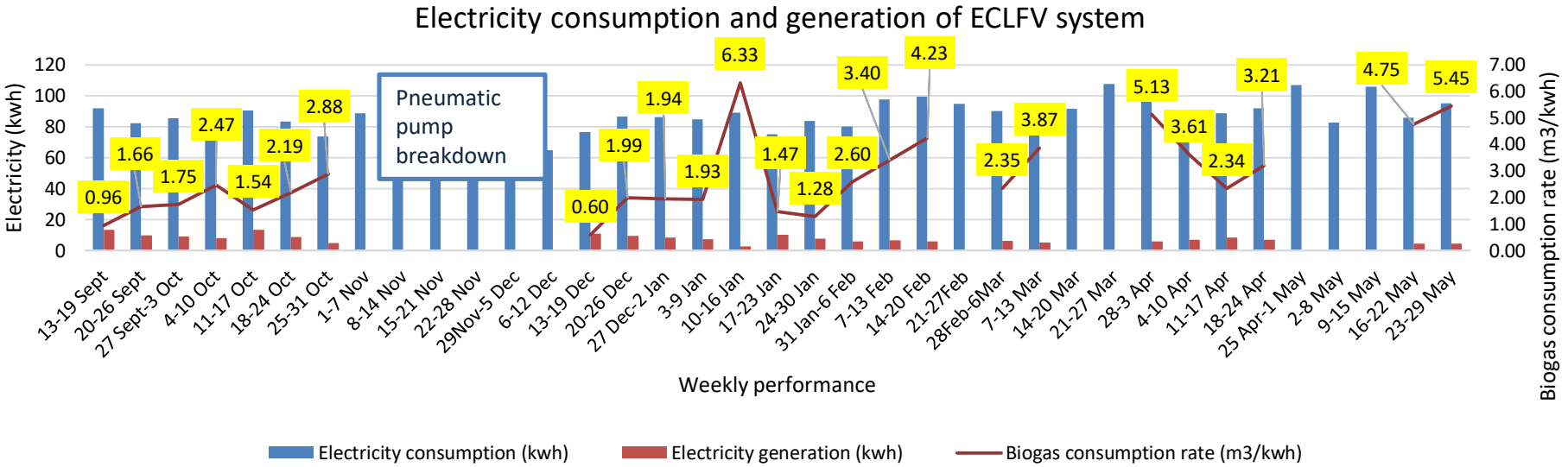
Parameter	Table waste	Kitchen waste
TS	20.33±0.19%	4.95±0.25%
VS	19.44±0.23%	4.05±0.15%
C (%TS)	51.98	36.89
H (%TS)	7.62	5.04
N (%TS)	4.04	3.56
S (%TS)	0.15	0.35
C/N ratio	12.87	10.36
P (%TS)	0.18	0.23
K (%TS)	0.60	4.36
Na (%TS)	1.09	0.18
Ca (%TS)	0.13	1.24
Mg (%TS)	0.04	0.20
Theoretical CH_4 yield (mL/gVS)	583.81	340.37
Theoretical CH_4 yield (L/kg waste)	111.95	14.12
Theoretical biogas yield (L/kg waste)	199.91 (CH_4 content 56%)	32.27 (CH_4 content 43.75%)

AD Performance



Food waste treated: 10195 kg
Biogas production: 878 m3
Average biogas yield: 86.2 L/kg Food waste (**high efficiency, >80%** of the biogas potential of the food waste)

Electricity Generation



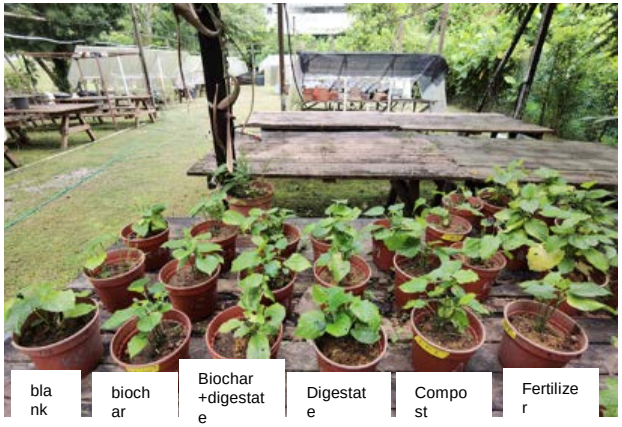
Energy balance:

Electricity generation: 194.6 kwh
Electricity consumption of the AD system: 3178.7 kwh
Average 85.9 kwh/week consumption *V.S.* 7.8 kwh/week generation
Average biogas consumption rate: 2.8m3/kwh

Main reason: low biogas engine efficiency (10%) and low CH4 content (55-60%) in the produced biogas.
As majority of FW fed was vegetable wastes (65-75%), where the biogas produced is of poorer quality (low VS)

Fertilizer for Plants

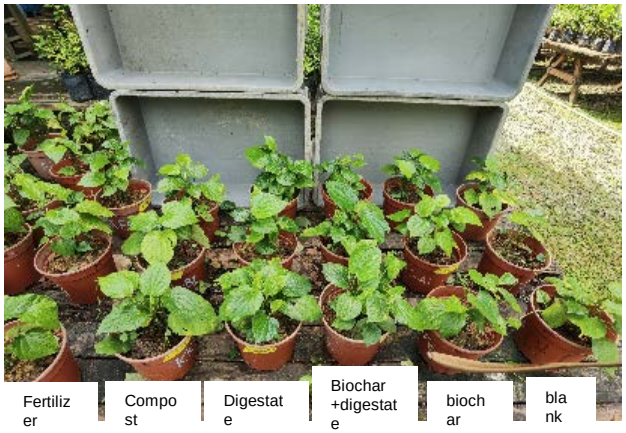
First day to apply N fertilizer

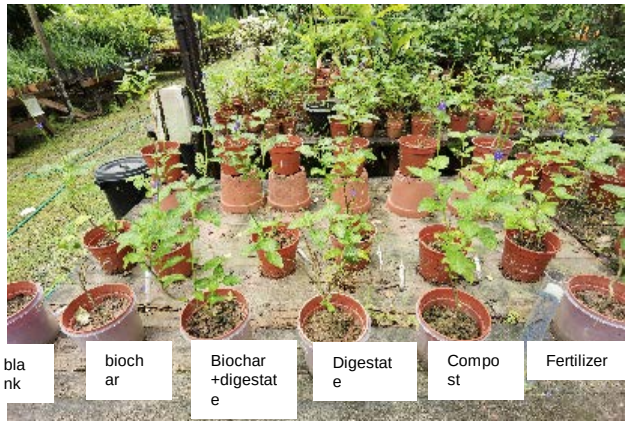


Piper sarmentosum

Stachytarpheta jamaicensis

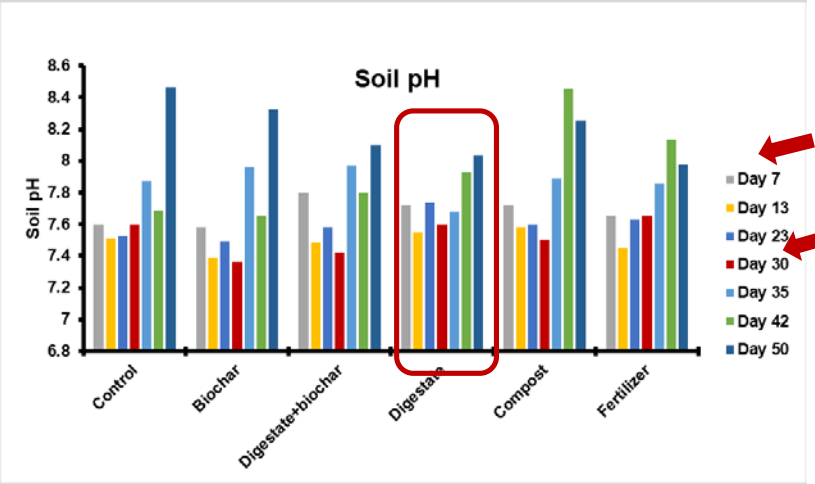
60 days later



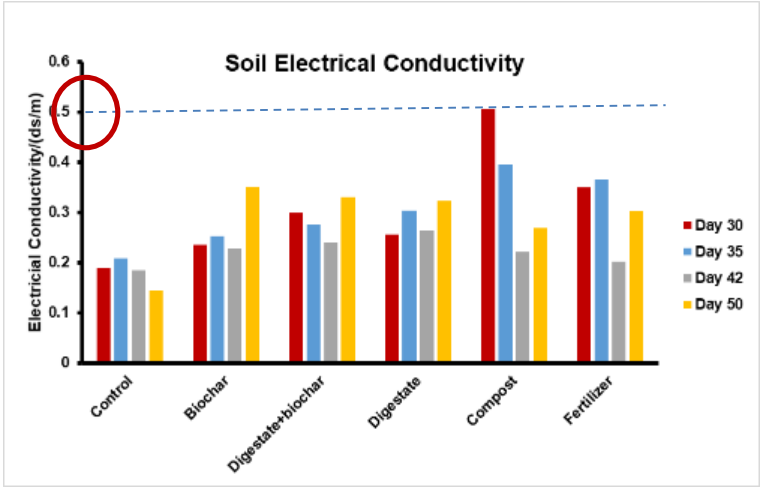


Plant Growth Performance

Stachytarpheta jamaicensis



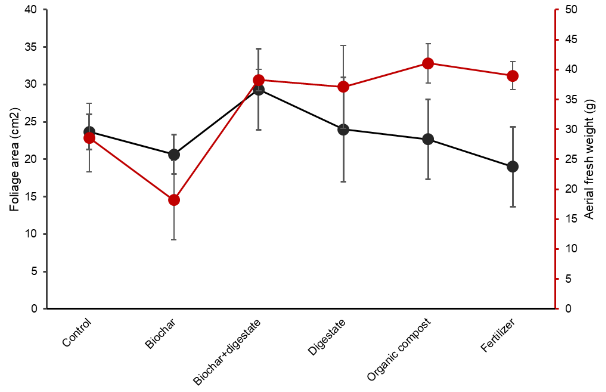
Digestate had no significant effect on pH in soil

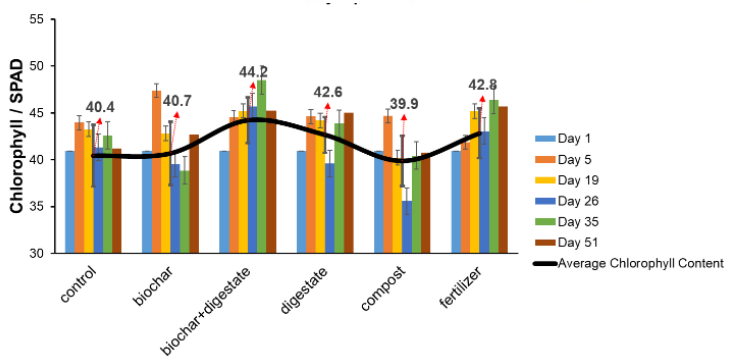


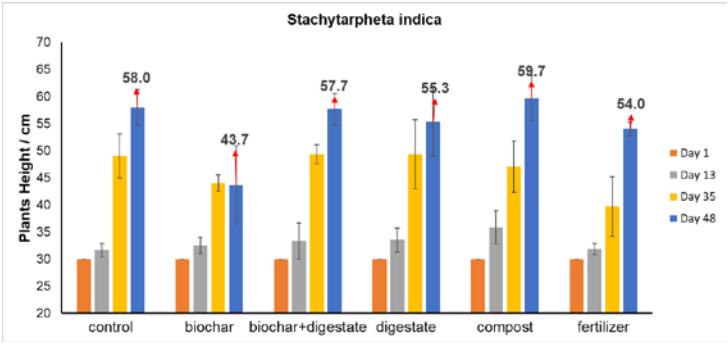
Digestate had no significant effect on soil EC

EC < 2dS/m represents NonSaline

Plant Growth Performance







Compared to compost and Fertilizer, digestate showed the similar positive effect on plants from the plant height, weight, and foliage area perspective.

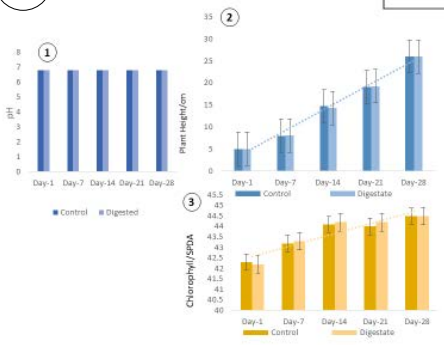
More Plants

Field Experimental Design

a

Experimental design for subtrial from February to March 2022 on *Betal piper*

Plant type	Treatment	Fertilizer	Media	Replicate
Betal piper	A	Blank	Soil	5
	B	Digestate	Soil	5



Results-
1. Digestate has no significant effect on soil pH is compared to normal soil pH.
2. Digestate has enhanced the growth of plants is compared to normal soil plant growth.
3. Digestate has no significant effect on chlorophyll (SPAD) content is compared to normal plant chlorophyll content.

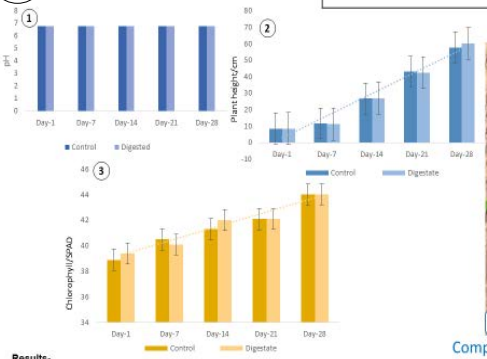
Compared to control, digestate showed a similar positive effect on plants from the plant's morphology area perspective.

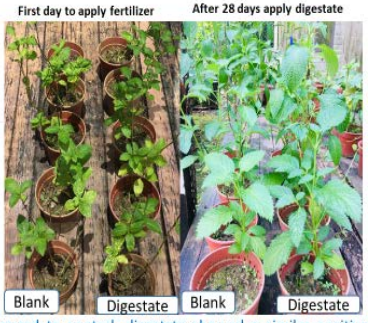
Field Experimental Design

b

Experimental design for subtrial from February to April 2022 on *Stachytarpheta jamaicensis*

Plant type	Treatment	Fertilizer	Media	Replicate
Piper sarmentosum	A	Blank	Soil	5
	B	Digestate	Soil	5





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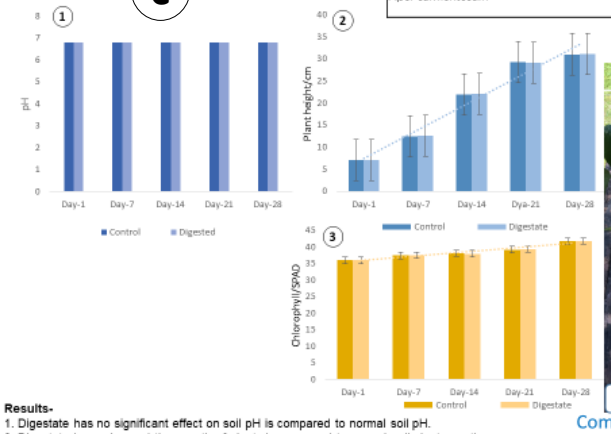
Compared to control, digestate showed a similar positive effect on plants from the plant's morphology area perspective.

Field Experimental Design

c

Experimental design for subtrial from February to March 2022 on *Piper sarmentosum*

Plant type	Treatment	Fertilizer	Media	Replicates
Piper sarmentosum	A	Blank	Soil	5
	B	Digestate	Soil	5



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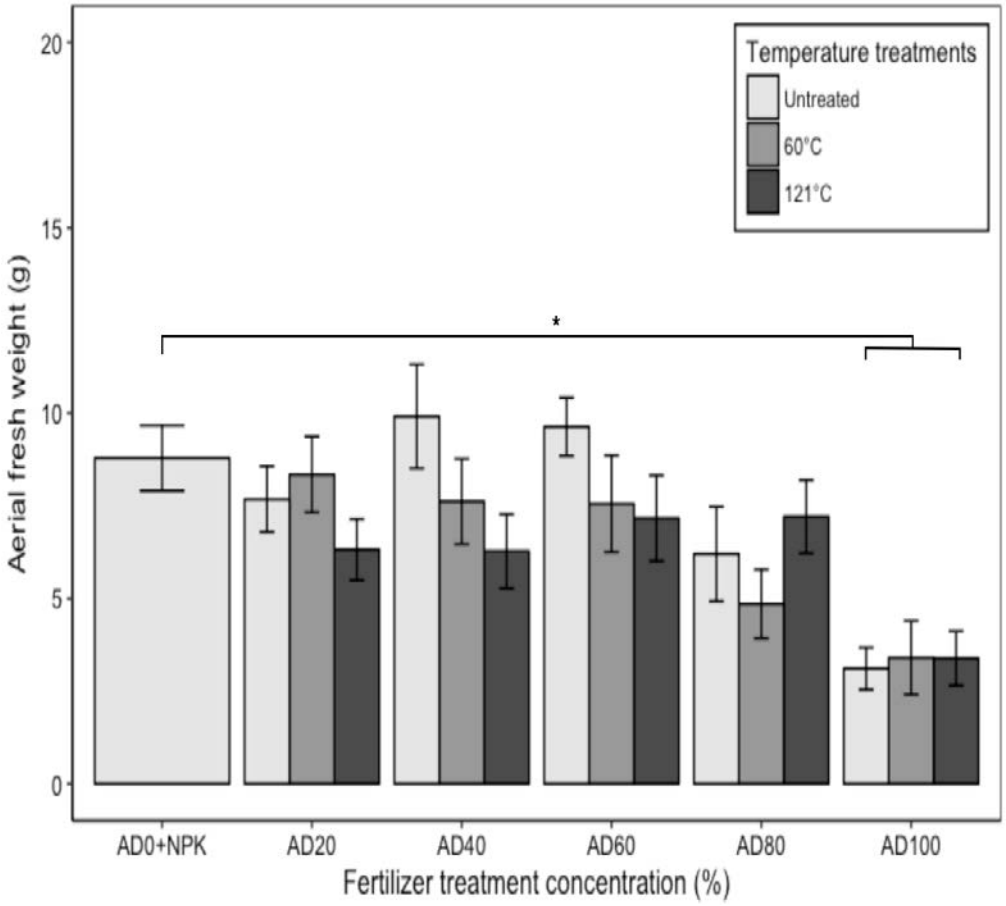
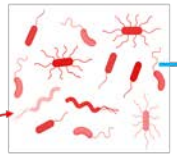
Compared to control, digestate showed a similar positive effect on plants from the plant's morphology area perspective.

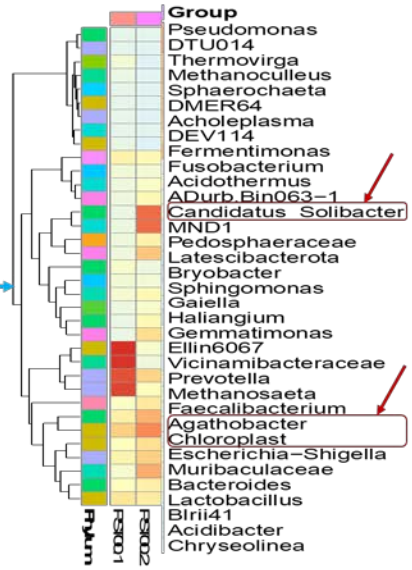
- Results revealed that the total chlorophyll contents and plant height also increase compared to control plants.

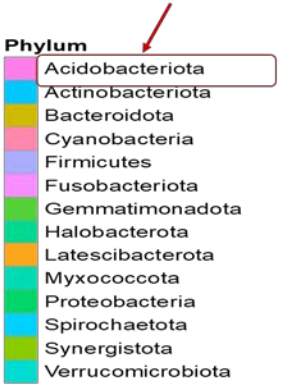
Growing Vegetables



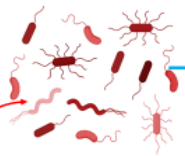
Digestate Microbial Community

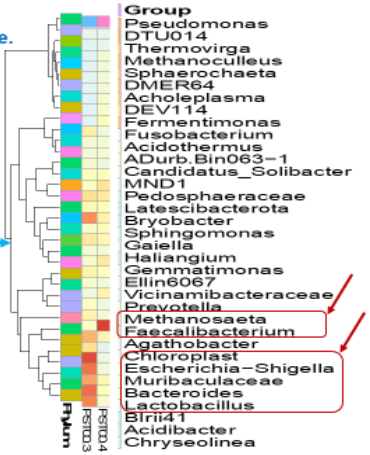


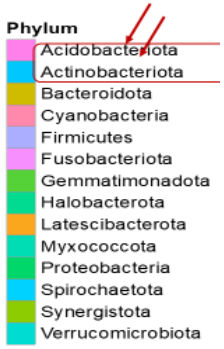




Metagenomic analysis of rhizospheric soil of *Piper sarmentosum* after and before applying the digestate.



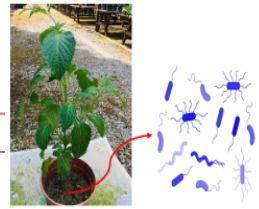


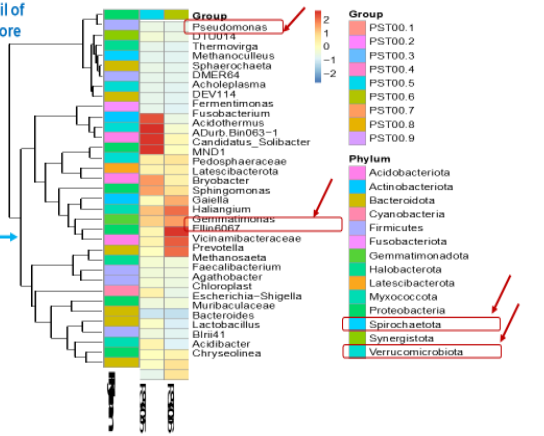


Results-

- The dominant group of bacteria is *Bacteroidetes*. *Bacteroidetes* are abundant pathogen-suppressing members of the plant microbiome that contribute prominently to rhizosphere phosphorus mobilization, a frequent growth-limiting nutrient in this niche.
- *Actinobacteria* improve the availability of nutrients and minerals, synthesized plant growth regulators, and specially, they are capable of inhibiting phytopathogens.

Metagenomic analysis of rhizospheric soil of *Stachytarpheta jamaicensis* after and before applying the digestate.

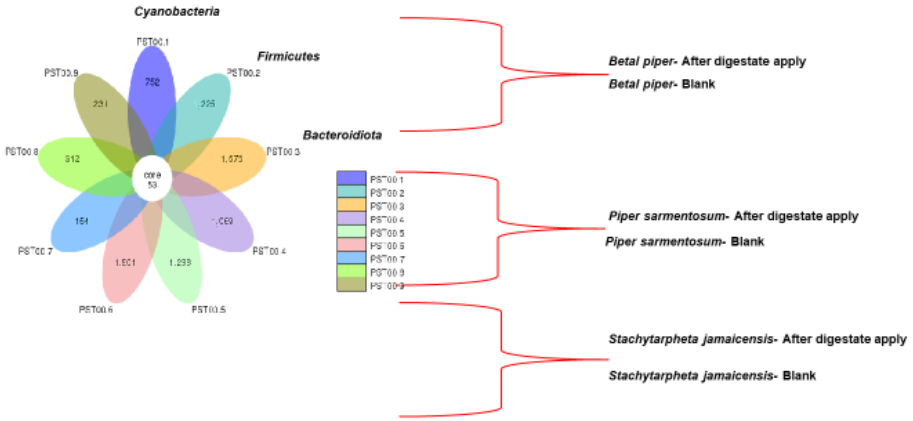




Results-

- Plant-associated *Pseudomonas* live as saprophytes and parasites on plant surfaces and inside plant tissues. Many plant-associated Pseudomonas promote plant growth by suppressing pathogenic micro-organisms, synthesizing growth-stimulating plant hormones and promoting increased plant disease resistance

Flower diagram of microbial community based on operational taxonomic units (OTUs)



Results-

Flower diagram based on OTUs. Each petal represents each sample. The core number in the center is for the number of OTUs present in all samples, while the number in the petal is for the unique OTUs in each sample.

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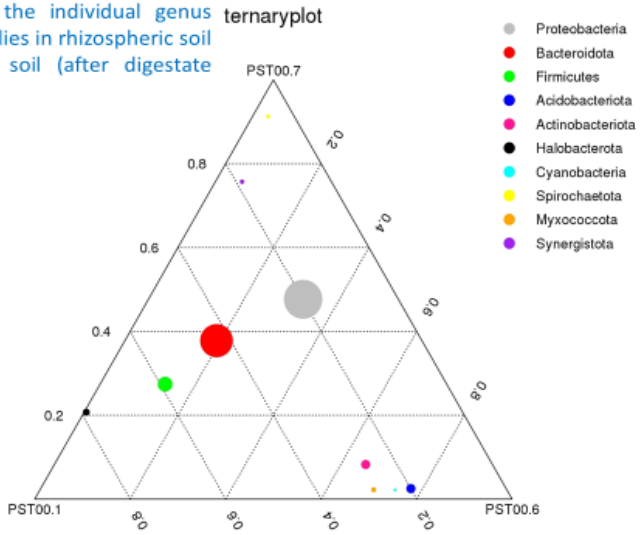
Expected output

1. Use food waste digestate as compost/biofertilizer for the development of public parks, agricultural lands, etc.
2. Development of a large-scale compost/biofertilizer from food waste digested for economical growth.

Ternary plot representing the relative occurrence of the individual genus (circles) that are members of the five most abundant families in rhizospheric soil (after digestate applied) compared with rhizosphere soil (after digestate applied).



Results-

Genera enriched in different compartments are colored by the taxonomy of the most abundant families. The size of the circles is proportional to the mean abundance in the community.

Conclusions

- Life Cycle Analysis being conducted for sustainability
- Cost Benefit Analysis is being done to show financial feasibility
- Behavioural changes needed
- Benefits to users on-site
- Many regulatory concerns to address
- Output of biogas, electricity and fertilizer to be quantified at steady-state

Thank you!