MONASH University Malaysia

6th International Conference on Sustainable Solid Waste Management (NAXOS2018)

Sustainable valorization of wastewater sludge into organic fertilizer through vermicomposting process

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Date : 15 June 2018

1. Introduction

- **Malaysia is the world's leading producers and exporter of palm oil products after Indonesia.**

- **Waste produced:**
  - **Oil palm trunks**
  - **Oil palm fronds**
  - **Empty fruit bunches**
  - **Palm kernel shell**
  - **Palm pressed fiber**
  - **Palm oil mill effluent (POME)**

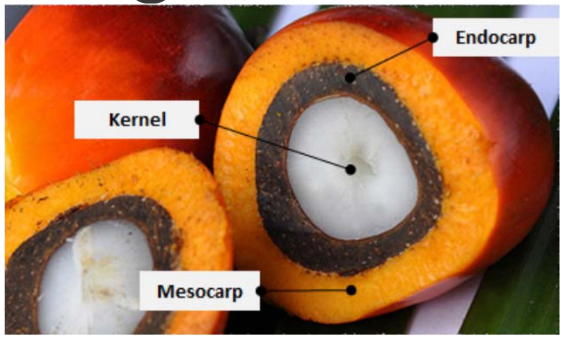
Solid Waste (oil palm trunks, oil palm fronds, empty fruit bunches, palm kernel shell, palm pressed fiber)

Liquid Waste (POME)

Adapted from thestar.com.my

Source: (Wu et al., 2007; Foo and Hameed, 2010)

Research Background - POME



Oil palm fruits

Palm oil extraction

Palm oil mill effluent (POME)

Ponding system of POME

= 1 tonnes CPO
~ 3 tonnes POME

= ~60 million tonnes of wet weight per year

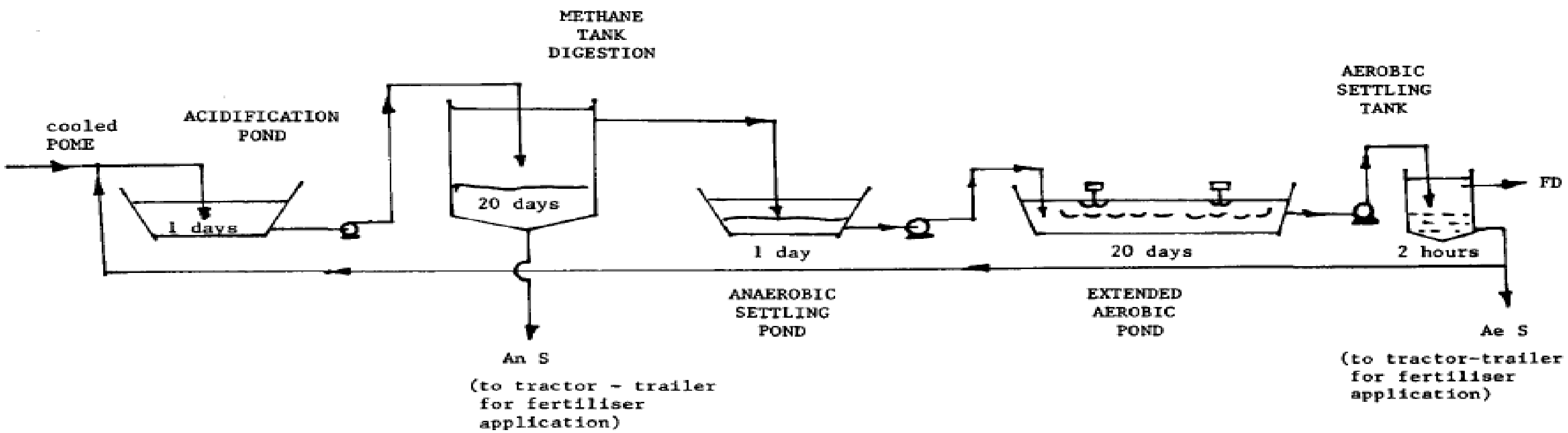
Characteristics of raw POME and the regulatory discharge limits

Parameters [a]	**Range** [c,f]	**Regulatory discharge limits** [d]
pH	4.2 - 4.7	5.0 – 9.0
Temperature (^{o}C)	80 - 90	45
Biochemical oxygen demand (BOD_3[b])	21,500 – 28,500	100 (50)
Chemical oxygen demand (COD)	45,500 – 65,000	-
Total suspended solids	15,660 – 23,560	400
Total Kjeldahl Nitrogen	750	200
C:N ratio	6.54	-
Calcium (Ca)	276 – 405	-
Magnesium (Mg)	254 – 344	-
Phosphorus (P)	94 – 131	-
Potassium (K)	1281 – 1928	-

[a]All values, except pH and temperature, are expressed in $mg.L^{-1}$
[b]The sample for BOD analysis is incubated at 30^{o}C for 3 days
Sources: [c](Ma, 2000), [d](Ahmad et al., 2003), [e](Wood et al., 1979; Wong et al., 2009), [f] (Wu et al., 2010)

Ponding System

- Most common treatment method
- 85% of the palm oil mills in Malaysia employed the ponding system to treat POME



Typical schematic diagram of ponding system (Ma and Ong, 1985)

Problem

- Sludge build-up

Current management methods

- Drying
- Land Application

Source: (Ma and Ong, 1985; Rupani et al., 2010)

Vermicomposting

- Natural conversion of biodegradable waste into organic fertilizer (Lee et al., 2018)

Earthworms & Microorganisms

Organic Waste + Amendments → Vermicompost (Organic Fertilizer)

Advantages of vermicomposting process (Lim et al., 2016):

- Shorter processing time
- High nutrients recovery

Benefits of vermicompost (Sim and Wu, 2010):

- Rich in nutrients
- Improve soil texture
- Improve plant growth

2. Research Objective

Research Objective

To bio-transform wastewater sludge produced from the (aerobic) treatment pond of POME into organic fertilizer using vermicomposting process.

3. Methodology

MONASH University
Malaysia

Research Methodology

- Earthworm species: *Eudrilus eugeniae*
- Vermicomposting duration: 11 weeks
- Feeding rate: 0.5 kg feed/kg worm/day
- Organic waste: POME sludge (S)
- Amendment: rice straw (R)
- Treatments: S, R, S1:R1, S1.5:R1, S2:R1, S1:R2

4. Stage 1: Preliminary Research

Summary of Results

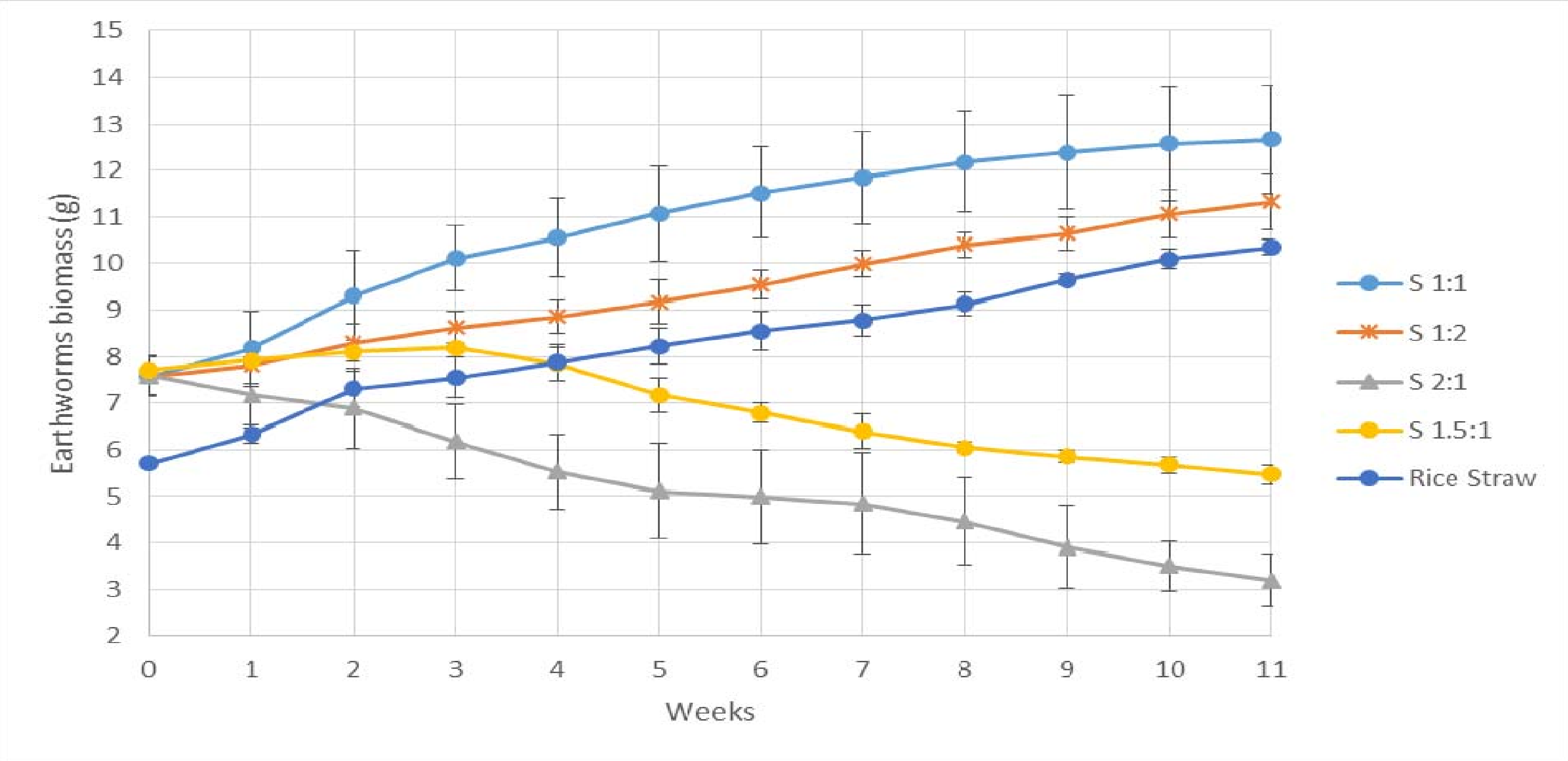
- ✓ Growth and reproduction of *Eudrilus eugeniae*
- ✓ Physico-chemical changes of vermicompost
    - pH
    - Electrical conductivity (EC)
    - C/N Ratio
    - Potassium, Magnesium, Calcium, Phosphorus

Description of the treatment for vermicomposting of wastewater sludge

Treatment	Description
RS	Pure rice straw
S 1:2	1 Wastewater Sludge : 2 Rice Straw
S 1:1	1 Wastewater Sludge : 1 Rice Straw
S 2:1	2 Wastewater Sludge : 1 Rice Straw
S 1.5:1	1.5 Wastewater Sludge : 1 Rice Straw

Growth and Reproduction of earthworm, *E. eugeniae*

❖ **Biomass of earthworms**



Biomass of earthworms in wastewater sludge treatment

Growth and Reproduction of earthworm, *E. eugeniae*

❖ Biomass of earthworms

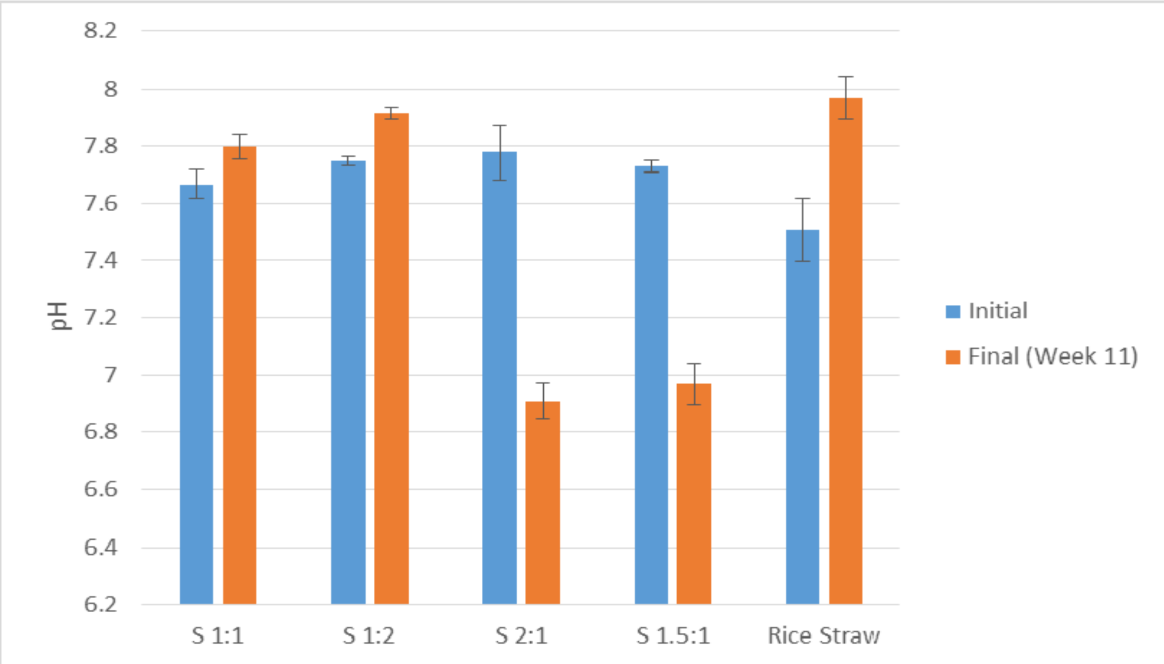
Earthworms biomass and density (number of individuals) in the initial and final vermicomposts for the different treatments (Mean ± SD, n = 3)[a]

Treatment	Initial feedstock		Final vermicompost	
	Earthworms biomass (g)	**No. of individuals**	**Earthworms biomass (g)**	**No. of individuals**
R	5.71 ± 0.01a	10 ± 0a	10.35 ± 0.17a	10 ± 0a
S1:R2	7.59 ± 0.42b	13 ± 0b	11.32 ± 0.60ab	13 ± 0b
S1:R1	7.59 ± 0.41b	13 ± 0b	12.67 ± 1.16b	13 ± 0b
S1.5:R1	7.72 ± 0.01b	13 ± 0b	5.46 ± 0.21c	9 ± 1a
S2:R1	7.60 ± 0.41b	13 ± 0b	3.19 ± 0.57d	7 ± 1c

[a] Mean values followed by different letters are statistically different (ANOVA, Turkey's test, $P < 0.05$).

Physico-chemical changes of vermicompost

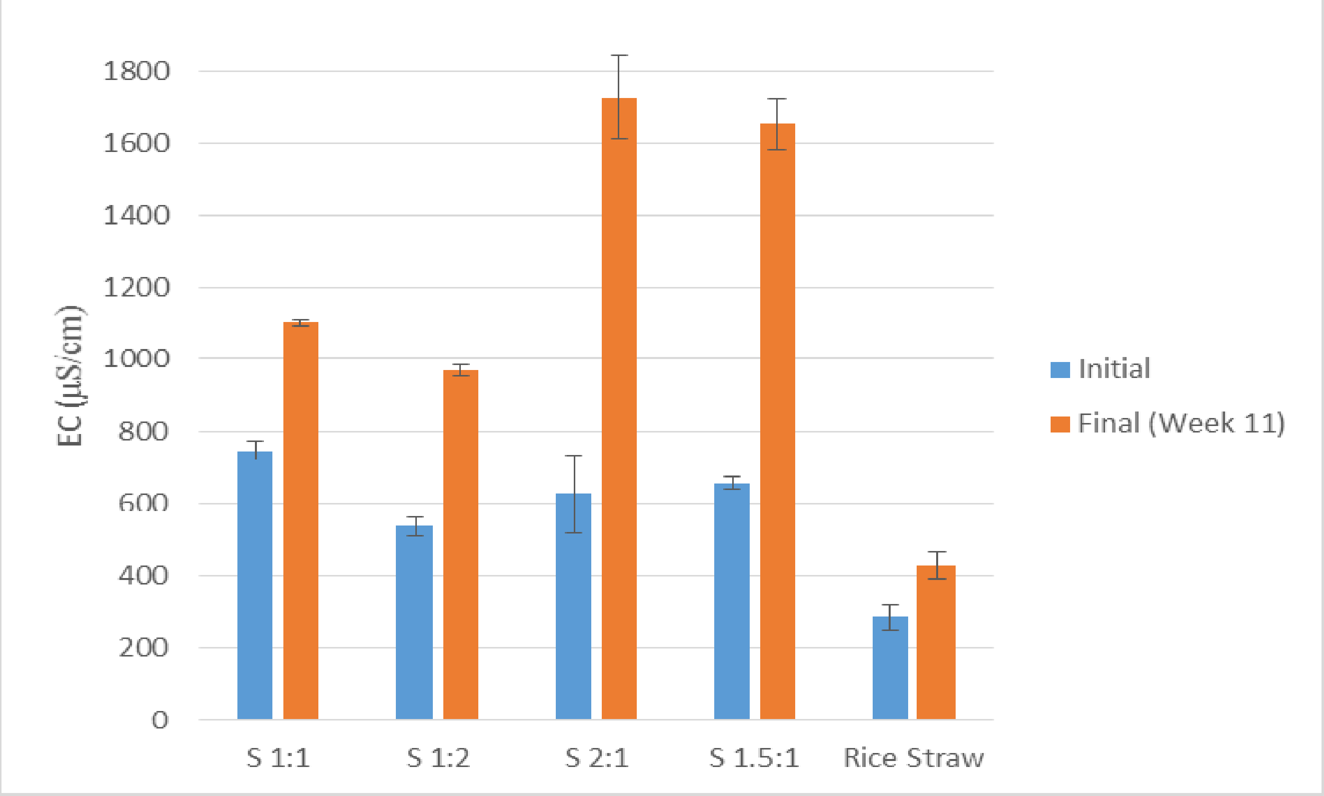
❖ pH



pH in wastewater sludge treatment

- Increase in pH: degradation of short fatty acid chains and intensive mineralization of nitrogen (Tognetti et al., 2007)
- Decrease in pH: production of CO_2 and organic acid (Lim et al., 2011)
- pH shift is dynamic and dependent on type of organic waste (Gupta and Garg, 2008)

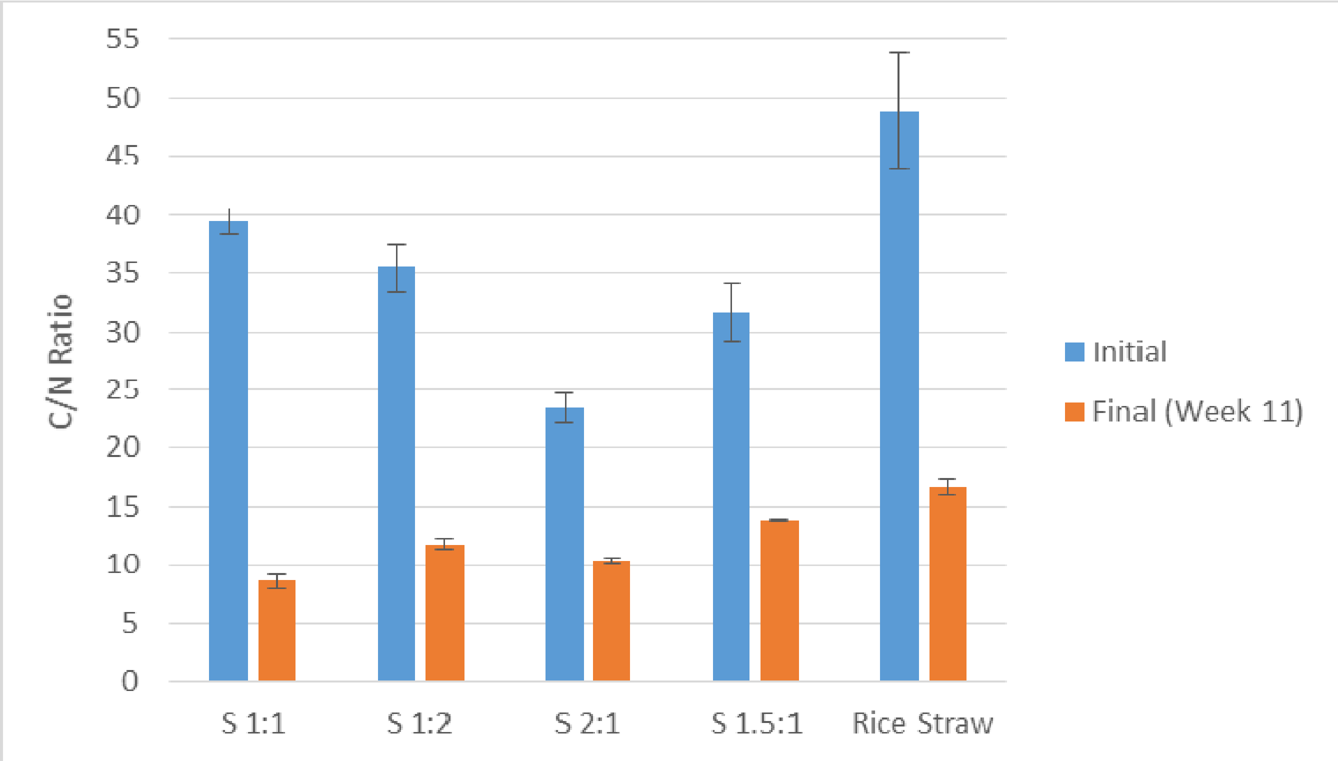
❖ Electrical Conductivity (EC)



Electrical conductivity (EC) in wastewater sludge treatment

- EC: salinity of organic amendment or total amount of dissolved ions available (Lim et al., 2012)
- Increase in EC: mineral salts were released in a more available form (Tognetti et al., 2007)

❖ C/N Ratio



C/N ratio in wastewater sludge treatment

- C/N ratio is used as indication of vermicompost maturation (Singh et al., 2011)
- Lower C content and higher N content show the maturity and stabilization of the vermicomposts
- Loss of carbon as CO_2 through respiration and increases of nitrogen content due to the production of mucus, enzyme as well as nitrogenous excrements by the earthworms

❖ Major nutrients (Potassium, Magnesium, Calcium, Phosphorus)

Initial chemical characteristics of waste mixtures (Mean ± SD, n = 3)

Treatment	Potassium (g/kg)	Magnesium (g/kg)	Calcium (g/kg)	Phosphorus (g/kg)
R	5.31 ± 0.31a	2.20 ± 0.10a	0.63 ± 0.06ab	1.75 ± 0.21a
S1:R2	8.45 ± 0.47bc	4.74 ± 0.26b	0.79 ± 0.08a	2.35 ± 0.07a
S1:R1	8.14 ± 0.07b	5.29 ± 0.10b	0.80 ± 0.01a	2.40 ± 0.49a
S1.5:R1	6.46 ± 0.17d	3.31 ± 0.23c	0.57 ± 0.05b	2.78 ± 0.39a
S2:R1	9.25 ± 0.35c	7.02 ± 0.24d	1.01 ± 0.06c	2.60 ± 0.49a

Final chemical characteristics of waste mixtures (Mean ± SD, n = 3)

Treatment	Potassium (g/kg)	Magnesium (g/kg)	Calcium (g/kg)	Phosphorus (g/kg)
R	5.56 ± 0.22a	2.76 ± 0.16a	0.74 ± 0.02a	2.60 ± 0.35a
S1:R2	9.26 ± 0.24b	7.31 ± 0.37b	0.99 ± 0.05b	4.48 ± 0.04b
S1:R1	9.91 ± 0.07c	8.85 ± 0.21c	1.18 ± 0.01c	3.85 ± 0.21ab
S1.5:R1	6.77 ± 0.14d	4.56 ± 0.20d	0.73 ± 0.01a	3.98 ± 0.39ab
S2:R1	9.93 ± 0.24c	9.95 ± 0.36e	1.16 ± 0.12bc	3.85 ± 0.57ab

[a] Mean values followed by different letters are statistically different (one-way ANOVA; Turkey's test, $P < 0.05$).

Stage 1 Conclusion

❖ Best treatment for the wastewater sludge

Table 3: Ratio of wastewater sludge to rice straw that produced the highest vermicompost quality

Parameters	S1:1 Treatment
Treatment description	1 wastewater sludge : 1 Rice straw
pH	7.80 ± 0.04
Electrical conductivity (µS/cm)	1102 ± 8.66
C/N	8.60 ± 0.62
Reduction of C/N (%)	78.2
Earthworms biomass (g)	12.67 ± 1.16
Increase of earthworm biomass (%)	67.1
Vermicomposting duration	11 weeks

5. Stage 2: Detailed vermicompost maturity and stability studies

Further evaluation of the maturity and stability of the vermicompost via instrumental characterization

- Combination of tests should be employed for assessment of maturity and stability of vermicompost
- Useful for determining the effectiveness of vermicomposting process in producing high quality organic fertilizer

Type of characterizations:

- Fourier transform infrared (FT-IR) spectroscopy
- Thermogravimetric (TG) analyzer
- Scanning electron microscopy (SEM)
- Brunauer-Emmett-Teller (BET) method

* This study is limited to the best ratio of wastewater sludge to rice straw determined from Stage 1 of the study

FT-IR

- Wave number: ranged from 4000 to 500 cm^{-1}.
- Functional groups: hydrogen bond O-H, aliphatic methylene peaks, aldehydes and organic esters peak, amines group C=O, C-O stretch of polysaccharides, cellulose and hemicellulose

TGA

- The samples were combusted from 30 to 1000ºC with a heating rate increment of 10ºC/min under air atmosphere.

SEM

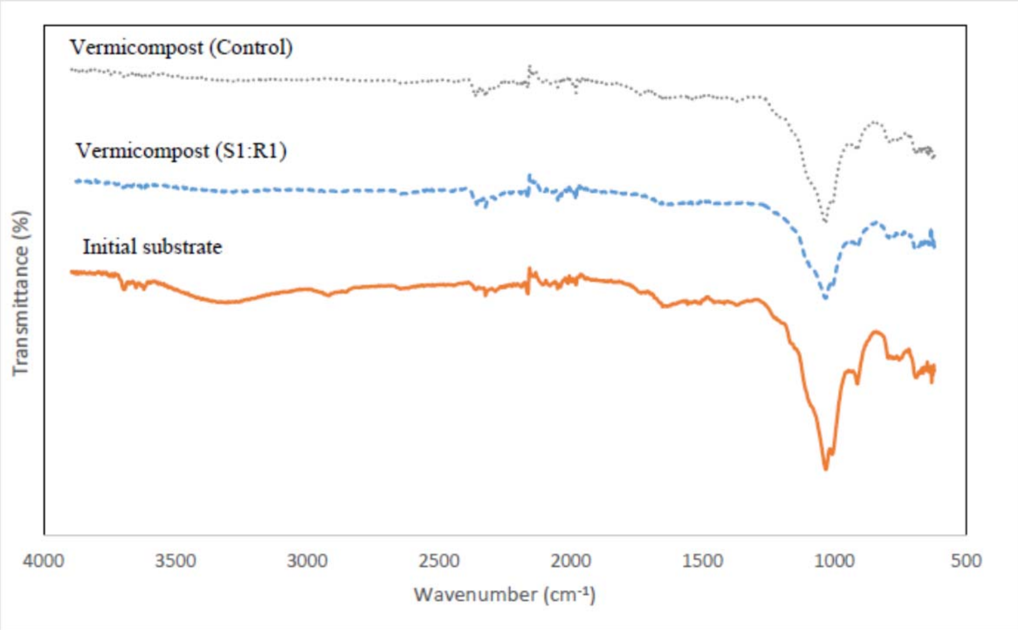
- Used to determine to microstructures and surface morphology of the samples

BET

- Brunauer-Emmett-Teller (BET) method
- By using N_2 gas as the adsorbate at 77.3K, the samples were degassed for 2 hours at 90ºC, subsequently 22 hours at 110ºC before the adsorption analysis.

Results and Discussions

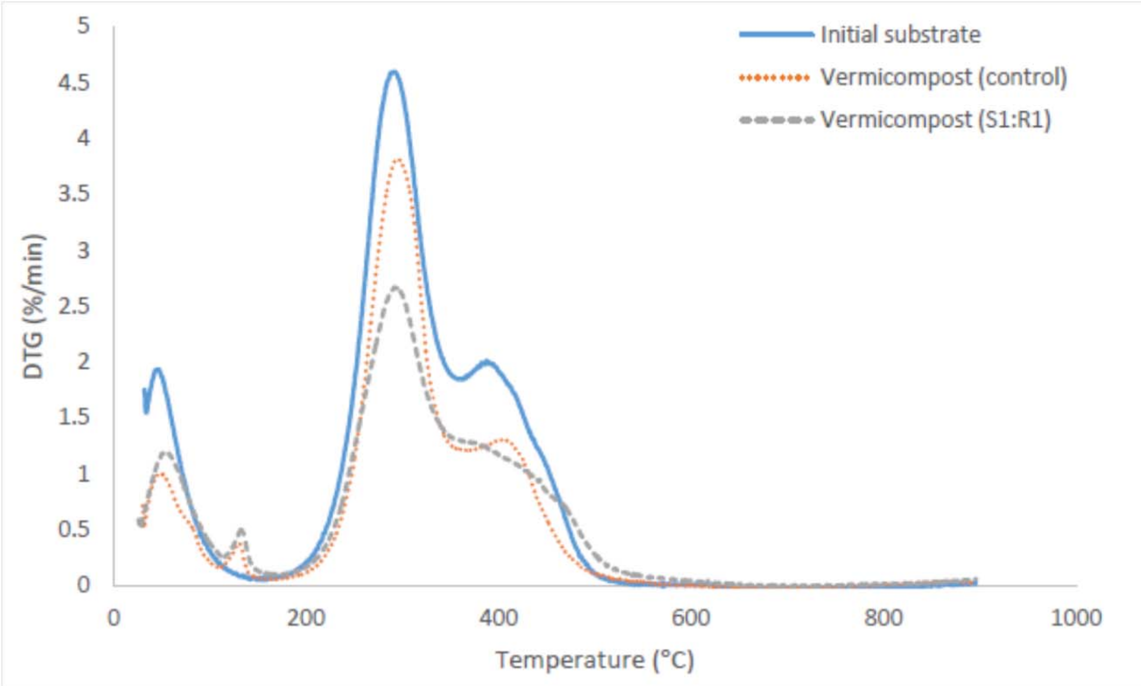
❖ Spectroscopic Analysis: FT-IR



FT-IR spectra

Wavenumber (cm^{-1})	Band assignment
~ 3200	Carboxylic group
2921	C-H stretch of aliphatic methylene group
1633	C=O stretch of amides
1034	C-O stretch of polysaccarides

❖ Thermogravimetry (TG) Analysis



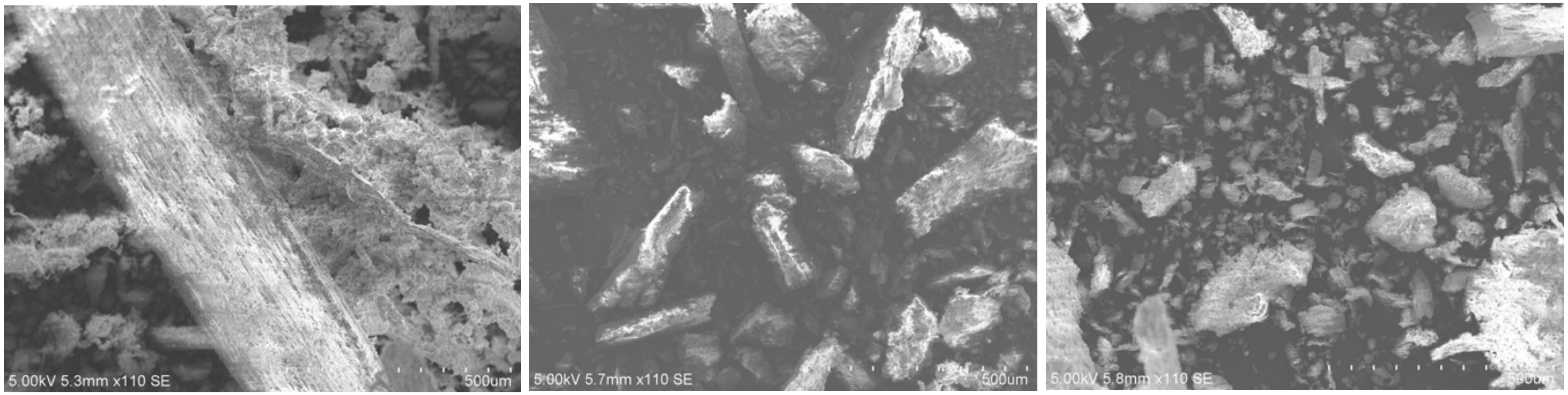
Differential thermogravimetric (DTG) curve

- DTG1 at 50ºC: dehydration of the residual water
- DTG2 at 280ºC: degradation of readily degradable materials and semivolatile compounds
- DTG3 at 400-600ºC: degradation of complex and condensed organic compounds; shifts toward higher temperature with increasing stabilization

(Lim et al., 2015; Wu et al., 2011)

5 Stage 2: Detailed vermicompost Maturity and Stability Studies (Continued…)

❖ Structural Analysis: BET and SEM



SEM images of (a) initial substrate, (b), vermicompost (control), (c), vermicompost (S1:R1)

	BET Surface Area (m^2/g)
Initial substrate	4.1155
Vermicompost (control)	7.3529
Vermicompost (S1:R1)	7.5574

6. Conclusion

- *E. eugeniae* were capable in transforming wastewater sludge obtained from the POME treatment pond into fertilizer via vermicomposting.
- Higher quality vermicompost was produced from S1:R1 treatment.
- The combined FT-IR and TG analysis showed a reduction in readily degradable materials such as carbohydrates, polysaccharides and aliphatic compounds.
- Structure characterization showed that the vermicompost was more fragmented and had larger surface area.

THANK YOU