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ชื่อโครงการ	**Utilization of Paper Cup Waste and Rain Tree (*Samanea saman*) Leaves by Vermicomposting Process with Cow Dung and Coffee Ground as Bulking Agent**
ชื่อนิสิต	**Miss Unchalika Klomklang**
ภาควิชา	**Environmental Science**
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คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย

SENIOR PROJECT

Project title	Utilization of Paper Cup Waste and Rain Tree (*Samanea saman*) Leaves by Vermicomposting Process with Cow Dung and Coffee Ground as Bulking Agent
Student name	Miss Unchalika Klomklang **Student ID** 583 33583 23
Department	Environmental Science
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Faculty of Science, Chulalongkorn University

Utilization of Paper Cup Waste and Rain Tree (*Samanea saman*) Leaves by Vermicomposting Process with Cow Dung and Coffee Ground as Bulking Agent

Unchalika Klomklang

A Senior Project Submitted in Partial Fulfillment of the Requirements for the Bachelor's Degree of Science Program in Environmental Science,

Department of Environmental Science,

Faculty of Science, Chulalongkorn University,

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Accepted by the Department of Environmental Science, Faculty of Science, Chulalongkorn University in Partial Fulfillment of the Requirements for the Bachelor's Degree

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หัวข้อ	**การประยุกต์ใช้ขยะถ้วยกระดาษและใบจามจุรีในการทำปุ๋ยหมักมูลไส้เดือน โดยมีมูลวัวและกากกาแฟเป็น Bulking agent**
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บทคัดย่อ

การศึกษาครั้งนี้มีวัตถุประสงค์เพื่อศึกษาอัตราส่วนที่เหมาะสมของขยะจากถ้วยกระดาษและใบจามจุรีในการทำปุ๋ยหมักมูลไส้เดือนดิน ร่วมกับมูลวัวและกากกาแฟเป็น bulking agents โดยใช้ไส้เดือนดินสายพันธุ์ *Eudrillus eageniae* ทำการหมักเป็นระยะเวลา 60 วัน จากการวิเคราะห์คุณสมบัติทางกายภาพและเคมี พบว่า เมื่อสิ้นสุดกระบวนการหมักปุ๋ยทุกชุดการทดลอง(T1-T5) มีค่าความเป็นกรด-ด่าง ค่าการนำไฟฟ้า และอัตราส่วนระหว่างคาร์บอนต่อไนโตรเจนอยู่ในช่วง 8.16-8.41, 1.24-1.55 เดซิซีเมนส์ต่อเมตร และ 2.36-2.71 ตามลำดับ ปริมาณอินทรีย์คาร์บอนทั้งหมดและปริมาณอินทรียวัตถุทั้งหมดมีค่ามากที่สุดในชุดการทดลองที่ 4 (T4) มีค่าเท่ากับ 33.47±0.56 % และ 57.56±0.96 % ตามลำดับ และมีค่าน้อยที่สุดในชุดการทดลองที่ 3 (T3) มีค่าเท่ากับ 32.09±0.61% และ 55.20±1.06% ตามลำดับ สำหรับธาตุอาหารหลัก ได้แก่ ปริมาณไนโตรเจนทั้งหมด ปริมาณฟอสฟอรัสที่เป็นประโยชน์ และปริมาณโพแทสเซียมที่แลกเปลี่ยนได้ พบว่า ปริมาณไนโตรเจนทั้งหมดมีค่ามากที่สุดในชุดการทดลองที่ 4 (T4) และน้อยที่สุดในชุดการทดลองที่ 1 (T1) มีค่าเท่ากับ 14.17±0.46 % และ 12.24±0.48% ตามลำดับ ปริมาณฟอสฟอรัสที่เป็นประโยชน์มีค่ามากที่สุดในชุดการทดลองที่ 1 (T1) และน้อยที่สุดในชุดการทดลองที่ 5 (T5) มีค่าเท่ากับ 1,418.08±305.45 ppm และ 472.69±57.98 ppm ตามลำดับ ปริมาณโพแทสเซียมที่แลกเปลี่ยนได้มีค่ามากที่สุดในชุดการทดลองที่ 1 (T1) และน้อยที่สุดในชุดการทดลองที่ 3 (T3) มีค่าเท่ากับ 8,146.81±739.40 ppm และ 3,861.98±1,024.56 ppm ตามลำดับ นอกจากนี้จากการทดสอบการงอกของเมล็ดข้าวโพดพบว่ามีค่ามากที่สุดในชุดการทดลองที่ 1 (T1) คือ 45.00±10.00% และมีค่าน้อยที่สุดในชุดการทดลองที่ 2 (T2) คือ 31.67±23.63% จากการเปรียบเทียบกับค่ามาตรฐานคุณภาพปุ๋ยอินทรีย์ของกรมวิชาการเกษตร (พ.ศ.2548) พบว่า ปุ๋ยที่ได้จากการทดลอง (T1-T5) สามารถช่วยในการปรังปรุงคุณสมบัติทางกายภาพของดินได้

คำสำคัญ: ปุ๋ยหมักมูลไส้เดือนดิน ขยะจากถ้วยกระดาษ ใบจามจุรี มูลวัว กากกาแฟ ไส้เดือนดินสายพันธุ์ *Eudrillus eageniae*

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Student name	Unchalika Klomklang **Student ID** 583 33583 23
Project Advisor	Associate Professor Nuta Supakata, Ph.D.
Co-Project Advisor	Assistant Professor Nuttakorn Intaravicha, Ph.D.
Department	Environmental Science
Academic year	2018

ABSTRACT

The objectives of this study were to determine the appropriate ratio of paper cup waste and rain tree leaves by vermicomposting process combined cow dung and coffee grounds as bulking agents using earthworms species *Eudrillus eageniae*. The vermicomposting was conducted for 60 days. From the analysis of physical and chemical properties found that all treatments (T1 to T5) on the final vermicomposting had the values of pH, EC and C/N ratio were in the range of 8.16-8.41, 1.24-1.55 dS/m and 2.36-2.71 respectively. The total organic carbon content and total organic matter content had the highest value in treatment 4 (T4) was 33.47 ± 0.56% and 57.56 ± 0.96% respectively and the lowest value in treatment 3 (T3) was 32.09 ± 0.61% and 55.20 ± 1.06% respectively. For the primary macronutrients, including total Kjeldahl nitrogen content available phosphorus content and exchangeable potassium content found that the total Kjeldahl nitrogen content had the highest in the treatment 4 (T4) and the lowest in treatment 1 (T1) with the value of 14.17 ± 0.46% and 12.24 ± 0.48% respectively. Available phosphorus content had the highest in the treatment 1 (T1) and the lowest in treatment 5 (T5) with the value of 1,418.08 ± 305.45 ppm and 472.69 ± 57.98 ppm respectively. Exchangeable potassium content had the highest in the treatment 1 (T1) and the lowest in treatment 3 (T3) with the value of 8,146.81 ± 739.40 ppm and 3,861.98 ± 1,024.56 ppm, respectively. In addition, the seed germination test found that the highest value in treatment 1 (T1) was 45.00 ± 10.00% and the lowest value in the treatment 2 (T2) was 31.67 ± 23.63%. The comparison with the compost quality standards of the Department of Agriculture (2005) presented that T1 to T5 can help improve the physical properties of the soil.

Keyword: Vermicomposting, Paper cup waste, Rain tree leaves, Cow dung, Coffee ground, *Eudrillus eageniae*

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Unchalika Klomklang

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Introductions

1.1 Background

Municipal solid waste (MSW) management is a major environmental issue in Thailand. In 2017, the amount of MSW was 27.40 million tons or 75,046 tons of MSW per day, 8.25 million tons of waste were recycled, representing 31% of total MSW, which left about 5.34 million tons of residue for disposal (Pollution Control Department, 2018). Waste utilization is a good choice for reducing that discarded residue.

Realizing the solid waste management issues at both national and international levels, Chulalongkorn University established the Chula Zero Waste Project a five-year plan to guide sustainable waste management within the university. In July 2018, Chula Zero Waste launched a closed-loop bioplastic management project to reduce waste from plastic glasses and straw by using paper cups coated with bioplastic, polylactic acid (PLA), which degrades in six months. Seven canteens at Chulalongkorn University reported the consumption of 690 kg of paper cups, or 63,600 cups, per month. This is a relatively high volume, meaning that the degrading time will be long (Chula Zero Waste, 2018).

Moreover, the rain trees (*Samanea saman*) on Chulalongkorn University's campus, which are over 25 meters high and can live more than 100 years, cause large quantities of waste all year long from shedding their leaves and branches (Kansai et al., 2017). Previous studies reported that mixing food scraps and rain tree leaves in compost is better than chemical fertilizer (considering the amount of grain produced). This mixed compost soil contains 1.25% nitrogen, 0.15% phosphorus, and 0.38% exchangeable potassium, whereas soil without fertilizer has 0.05%, 0.01%, and 0.02% of nitrogen, phosphorus, and potassium, respectively (Suntararak, 2014).

Composting, especially vermicomposting, is one of the best way to manage compostable waste. Vermicomposting is technology that involves the biological decomposition and stabilization of organic matter through the interaction of earthworms and microorganisms. They transform physicochemical and biochemical properties of organic matter at a faster rate than composting alone (Lim et al., 2016). According to Arumugam et al. (2018) vermicomposting can degrade paper cup waste and change it to high quality vermicompost with high nitrogen, phosphorus, and potassium content. Bulking agents play an important role in controlling the various factors of composting, such as controlling moisture content, increasing biodegradation, and reducing the time of the composting or vermicomposting process. There are several bulking agents that are often used in composting or vermicomposting processes. Cow dung is a popular bulking agent because it is widely found around the world, especially in agricultural countries like Thailand. Furthermore, this bulking agent can control moisture, bulk density, and C/N ratio (Batham et al., 2013). Moreover, the Department of Business Development (2017) reported that the expansion of Thailand's coffee business increased the market value of roasted coffee and instant coffee 7.3% annually in the last five years, resulting in increased coffee consumption among the Thai population, especially teenagers, which has increased coffee ground waste. To reduce the amount of waste taken to landfills, coffee grounds can be used as a supplementary material for composting with cow dung (Zhang et al., 2017).

This research uses vermicomposting to manage waste from rain tree leaves and paper cups generated at Chulalongkorn University, combining cow dung with coffee grounds as a bulk agent.

1.2 Objectives

To study the optimal paper cup waste and rain tree leaves ratio in vermicomposting by analyzing their physical and chemical properties.

1.3 Expected Benefits

1.3.1 Finding a suitable vermicompost ratio from paper cup waste and rain tree (*Samanea saman*) leaves.

1.3.2 Utilization of organic waste at Chulalongkorn University as raw material for vermicomposting with economic and environmental friendliness.

Chapter 2
Theory and literature review

2.1 Raw material

2.1.1 Paper cup waste (PCW)

According to Chula Zero Waste, in 2018 reported that seven canteens at Chulalongkorn University reported the consumption of 690 kg of paper cups, or 63,600 cups, per month. Normally, paper cup is made from 95% of high strength paper and coated by 5% of polyethylene (Arumugam et al., 2018). Nevertheless, Chula Zero Waste paper cup is coated by polylactic acid (PLA) which made from corn so it is able to degrade in soil (Harst et al., 2013). Based on the study of paper cup waste degradation by vermicomposting of Arumugam et al. (2018) found that the better quality vermicompost with an increased nutrient content (Magnesium, Calcium, Potassium, Phosphorus, and Nitrogen).

2.1.2 Rain tree leaves (RTL)

Rain tree is normally distributed in tropical regions including throughout Thailand. There are Legume species located in Sub-Family Mimosaceae and has a botanical name that Samanea saman Jacq Merr. This tree is a deciduous perennial plant and has canopy wide like an umbrella (Thongkhamsamoot, 2018). Rain trees have a height of about 15-25 meters and can last up to 100 years. There are a shade tree on the park or along roads and these large trees shed leaves on Chulalongkorn University's campus all year long, and their leaves and twigs are considered to be waste (Kansai et al., 2017). According to Suntararak, 2014 reported that the mixed food scraps and rain tree leaves compost is effective against of Grain yield of sticky rice in RD 6 rice variety.

2.1.3 Cow dung (CD)

According to the statistical data of the Department of Livestock Development report that in 2018, Thailand has raised increased beef cattle and dairy cattle. There are 5,445,351 beef cattle and 623,427 dairy cattle (Department of Livestock Development, 2018) which resulted in a large amount of waste from cow dung. Because one cattle will be able to excrete 4 to 5 percent of the body weight (Chotipalakul, 2000). Those cattle excrete 29 and 50 kilograms of cow dung/day respectively (Wongpichet, 2014).

Cow dung has nutrients that are essential to plant growth it contains 1.10 % nitrogen 0.04 % phosphorus and 1.60 % potassium (Tancho, 2006). Moreover, there are various microorganisms and enzymes that help in composting which can increase the degradation rate (Zhang et al., 2017).

2.1.4 Coffee grounds (CG)

The coffee industry in Thailand in 2018 has a production capacity of 20,000 tons of coffee per year, but there are not enough for the consumption of Thai people with coffee consumption up to 120,000 tons per year. It is predicted that the coffee consumption in 2022 will be higher to 300,000 tonnes per year that cause 290,000 tons of coffee waste per year (Tantiwattanapan, 2019). There are 20 coffee shop in Chulalongkorn University, each shop has 15-20 Kg of coffee ground per day (Kansai et al., 2017)

Polysaccharide is the most element in coffee grounds which is in the form of hemicellulose and lignin (Ballesteros et al., 2014). Moreover, coffee grounds contain more than 10 % of Nitrogen-rich proteins, and has a low carbon-to-nitrogen ratio of 11:1 which is the suitable ratio for plant and soil (Chalker-Scott, 2009).

2.2 Theory

2.2.1 Composting

Composting is one of making organic fertilizer that biodegrade organic waste both in aerobic and anaerobic environmental conditions. Organic waste is used by thermophilic and mesophilic microorganisms and then transform to the other compounds such as CO_2, H_2O and NH_4^+ or stabilized organic matters. Final compost is stable, humus-rich, can improve soil quality (Lim et al., 2016), odorless, disintegrating, easily broken, has dark brown color, has low C/N ratio and contains abundant plant nutrients (Srisatit, 2015). The compost equation is shown as equation 1:

$$\begin{array}{c} CHONPS+O_2+H_2O+Nutrient+Microorganisms \\ \downarrow \\ Compost\ new\ cells\ of\ microorganisms+CO_2+H_2O+NH_3+SO_4^{2-}+Heat \end{array} \quad \text{(equation 1)}$$

To make high quality and mature compost, it depended on several influencing factors viz:

1. Particle size of solid waste at the beginning stage should be 1-5 centimeters in size so that the microorganisms can decompose easily and quickly. If it is too large, the degradation will occur slowly and if it is too small, it causes poor ventilation (Srisatit, 2015).

2. Moisture content is essential for degradation of organic matter by microorganism. The microorganisms use water in composting process thus this process should have 40-65% of moisture content. If moisture content is less than 20%, microorganisms will be died and if moisture content is more than 80%, it causes poor ventilation like the small particles. Three ways to reduce moisture content are as follow:

- Add low moisture material
- Add saw dust
- Turn over the composting windrow

3. Temperature of the composting windrow have 3 phases: mesophilic phase at 25-45 degree Celsius, thermophilic phase at 45-70 degree Celsius and maturation phase which indicates that compost is stable and ready to use. The increment in temperature indicates that increase in microbial activity and temperatures up to 55 degrees Celsius are important for the removal of pathogen (Lim et al., 2016). After thermophilic phase, temperature will decrease to ambient temperature that is maturation phase so according to decreasing degradation of composting process.

4. pH throughout the process must be 5.5-9 that suitable for microorganisms to degrade organic matter. If pH is below 5.5, it indicates that too acidic so that should add more calcium carbonate ($CaCO_3$). Sour fruit will be added into composting windrow to reduce pH, if pH is more 8.

5. Nutrient level for microorganisms, both macronutrient and micronutrient, such as carbon, nitrogen, phosphorus, potassium, calcium, chloride, copper, iron, etc. The nutrient content should be enough for the needs of microorganisms, but there should not be too much because it can harm microorganisms. Especially, nitrogen that can transform to ammonia which harmful to microorganisms.

6. Time of composting process depend on composting technique. Aerobic composting spend time less than anaerobic composting.

7. Enough oxygen content is necessary for aerobic digestion. Composting is aerobic digestion that microorganisms use oxygen in respiratory system. If composting contain poor oxygen, composting will be anaerobic digestion and have to spent a lot of time.

2.2.2 Vermicomposting

Vermicomposting is the making organic fertilizer similar to composting. Unlike composting, vermicomposting uses earthworms along with microorganisms to degrade organic matter at a faster rate. To help the microorganisms degrade organic matter better, earthworms act as the main drivers to decompose organic matter into smaller sizes and enlarge the surface area. Vermicompost has low C/N ratio, high porosity, water-holding capacity and available nutrients. However, the efficiency of vermicomposting process is influenced by several factors such as initial C/N ratio, moisture content, pH, characteristics of waste, etc. Vermicomposting result are earthworm cast or vermicompost and new earthworm that propagated during vermicomposting process. After this process, the earthworms will be separated by light, vertical or sideways separation. The removed earthworms will be used to decompose other waste, as protein source for animals and fishing bait (Lim et al., 2016)

Vermicomposting process need earthworm to decompose organic waste. There are three different groups of earthworms: epigeic, endogeic and anecic (Lim et al., 2016). Epigeic earthworms have high reproductive rate and growing rate. They live in the surface soil. Endogeic earthworms live in Mineral soil horizon or top soil. These earthworms eat soil and mineral so they get a lot of nutrient of humus and organic matter in soil. Finally, anecic earthworms live in permanent hole in deep soil but they eat tree leaves and organic matter on topsoil (Tancho, 2006).

Eudrillus eageniae is epigeic earthworms. Their common name is African Night Crawler. These earthworms have quite large size but can move rapidly. They reproduce sexually at night under topsoil and generate 162-188 cocoon/year for each earthworm. Their habitat is tropical area therefore they prefer high temperature. They are able to grow fast but slowly at low temperature (under 16 degree celsius) (Tancho, 2006).

2.2.3 Compost quality standard

According to the announcement of the Department of Agriculture on Organic Fertilizer Standards 2005, there are 11 parameters of both physical and chemical standards (Srisatit, 2015). As follow in Table 2.1:

Table 2.1 Compost quality standard (Srisatit, 2015)

No.	Items	Criteria
1.	Fertilizer particles	≤ 12.5 x 12.5 mm
2.	Moisture and evaporable substance	≤ 35 %
3.	Rocks and gravels larger than size 5 mm	≤ 5 % by weight
4.	Plastic, glass, sharp particles and other metal parts	none
5.	Organic Matters (OM)	≥ 30 % by weight
6.	pH	5.5 – 8.5
7.	Carbon : Nitrogen ratio	≤ 20 : 1
8.	Electrical Conductivity	≤ 6 dS / m
9.	Primary nutrients: - Total nitrogen (N) - Total phosphorus (as P_2O_5) - Total potassium (as K_2O)	 ≥ 1.0 % by weight or 10000 ppm ≥ 0.5 % by weight or 5000 ppm ≥ 0.5 % by weight or 5000 ppm
10.	Complete decomposition	≥ 80 %
11.	Heavy metals - Arsenic - Cadmium - Chromium - Copper - Lead - Mercury	 ≤ 50 mg / kg ≤ 5 mg / kg ≤ 300 mg / kg ≤ 500 mg / kg ≤ 500 mg / kg ≤ 2 mg / kg

2.3 Literature review

Zhi-wei et al. (2019) reported that the earthworm has the ability to utilize organic waste as carbon/energy sources and convert into their biomass.

Khatua et al. (2018) found that the microflora in the gut and cast of earthworms along with secreted mucus plays an important role in increasing potassium content in vermicomposting as well as increasing the phosphorus and potassium content.

Negi et al. (2018) presented that the increase in TKN was caused by nitrogen immobilization in compost. Also, the mineralization of organic nitrogen through ammonification, ammonium volatilization and CO_2 emission increased nitrogen contents in the final vermicompost.

Suntararak (2014) indicated that mixing food scraps and rain tree leaves in compost is better than chemical fertilizer (considering the amount of grain produced). This mixed compost soil contains 1.25% nitrogen, 0.15% phosphorus, and 0.38% exchangeable potassium, whereas soil without fertilizer has 0.05%, 0.01%, and 0.02% of nitrogen, phosphorus, and potassium, respectively

Batham et al. (2013) reported the vermicompost must have bulking agents to enhance the degradation process. Bulking agents have many important functions in composting and vermicomposting processes, such as controlling the pH, moisture content, bulk density, carbon to nitrogen ratio, and aeration.

Pramanik et al. (2007) reported that during vermicomposting, the pH value decreased due to the degradation of organic matter by microorganisms caused produce of CO_2, ammonium ions, NO_3^-, and organic acids especially humic acid which presence carboxylic and phenolic groups affected to lower pH values while ammonium ions increased the pH values in the system. Therefore, the combined effect of these two oppositely charged ions controls the pH vermicomposts to a shift of pH towards neutrality.

Chapter 3
Materials and Methods

3. Materials and methods

3.1. Raw material collection and preparation

The paper cup waste was collected from the Chula Zero Waste Project, Chulalongkorn University, and then cleaned with water and cut into 2-cm-long pieces. The rain tree leaves are collected from the Chulalongkorn University campus. Both raw materials are dried in the oven at 70 °C to a constant weight (Wu et al., 2018). The vermicompost must have bulking agents to enhance the degradation process. Bulking agents have many important functions in composting and vermicomposting processes, such as controlling the pH, moisture content, bulk density, carbon to nitrogen ratio, and aeration (Batham et al., 2013). Cow dung brought from Thunhikorn shop and coffee ground were obtained from Terracotta coffee shop, Chulalongkorn University. These bulking agents were dried under sunlight for a week (Lim et al., 2016). All raw materials and bulking agents were physical-chemical analyzed before experimentation (Table 3.1).

Table 3.1 Analytical methods for physical-chemical properties

Parameters	Instrument/Method
C/N Ratio	Using results from TOC and TKN analysis
pH	pH meter (UB-10 Denver)
EC(ds/m)	Conductivity meter (Hach Senion156)
TKN (%)	Kjeldahl method (Kjelflex k-360)
Available P (ppm)	Ascorbic acid sulfomolybdo-phosphate blue color method (Spectrophotometer, Spectro sc)
Exchangeable K(ppm)	Atomic Absorption Spectrophotometry (Agilent, 240AA)
TOC (%)	Total organic carbon analyzer with Solid Analyzer (SHIMADZU, TOCVCPH)
TOM (%)	Using results from TOC

The adult epigeic earthworm (*Eudrillus eugeinea*) was obtained from Baan Sai Duean Farm, Bangkok, Thailand. Epigeic earthworm were the most suitable earthworms group to use in vermicomposting process because they have the most degradation efficiency, are widely distributed throughout the world, and have wide environmental tolerance (Lim et al., 2016).

3.2. Experimental design

To study the appropriate ratios of paper cup waste and rain tree leaves, this study used earthworm and microbial activators (PD1) for activate the vermicomposting process and cow dung and coffee ground mixture as bulking agent. There are five treatments and three replicates of each treatment using Completely Randomized Design (CRD). The composition of vermicomposting materials were tested with different ratio is shown in Table 3.2

Table 3.2 Composition of vermicomposting materials in different treatments

Treatment	**Composition (g)**				**[2]C/N Ratio**
	Paper cup waste	Rain tree leaves	[1]Cow dung	[1]Coffee ground	
T1	1000	0	200	450	30
T2	950	50	200	450	30
T3	900	100	200	450	30
T4	850	150	200	450	30
T5	800	200	200	450	30

[1]proper ratio of cow dung and coffee ground as bulking agent used in composting or vermicomposting (Zhang & Sun, 2017).
[2] C/N ratio of raw materials; Total Kjeldahl nitrogen calculated by Land Development Department, 2010

All of raw materials in each replicate was carried out in 20 liter plastic containers (29.5 cm in diameter and 38.2 cm in height) (Figure 3.1). After mixing all raw materials, adjust the ratio of carbon-to-nitrogen at the initial vermicomposting to 30 and add microbial activators (PD1). Then, leave them 17 days or until the temperature in the vermicompost pile decreased for equilibration and gas elimination (turn over every day). Then, 30 g of adult worms of the same size were released to each treatment. All treatments are placed on wood pallets in the trail area for 60 days and covered with a container lid, as shown in Figure 3.2 and 3.3

During the vermicomposting, various factors will be controlled:

(1) Moisture content should be maintained in the range of 40-65%. If moisture content is lower than 40%, water must be sprayed into the treatment. If moisture content is higher than 65%, the vermicompost seems to be turned over for the water in the treatment to evaporate.

(2) pH should be in range of 5.5–9 throughout the vermicomposting period. Generally, the pH in vermicomposting will slightly decrease. If the value is lower than 5.5, add lime ($CaCO_3$) to increase the pH to the appropriate range.

(3) Vermicomposting is an aerobic degradation process that helps microorganisms to completely decompose. If there is not enough oxygen, it will cause an anaerobic digestion process that may cause odor problems. To add oxygen to the treatments, turn over the vermicompost every day (Srisatit, 2015). Furthermore, turning over the vermicompost can help to eliminate volatile gases that were toxic to the earthworms (Zhang et al., 2018).

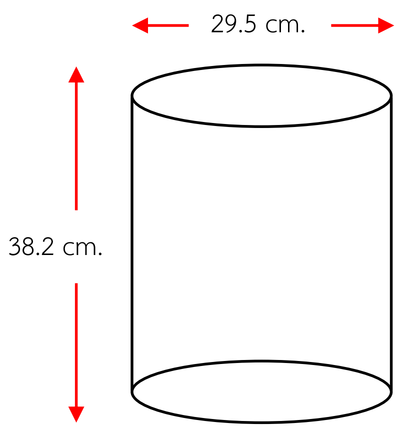


Figure 3.1 Plastic container for vermicomposting

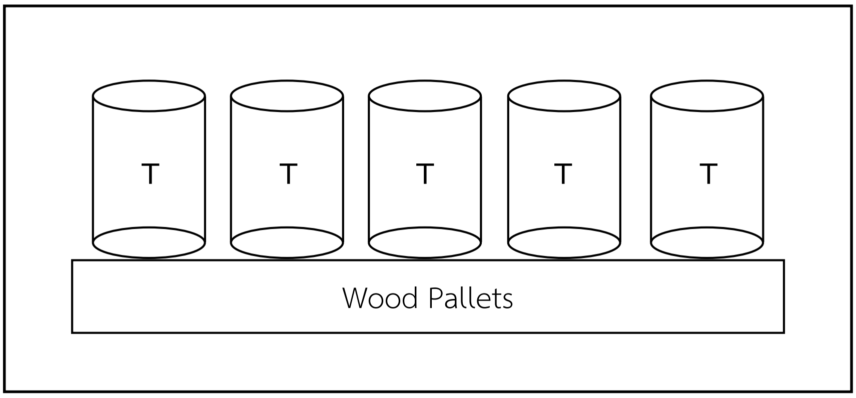


Figure 3.2 Side view of arranging container in trial area

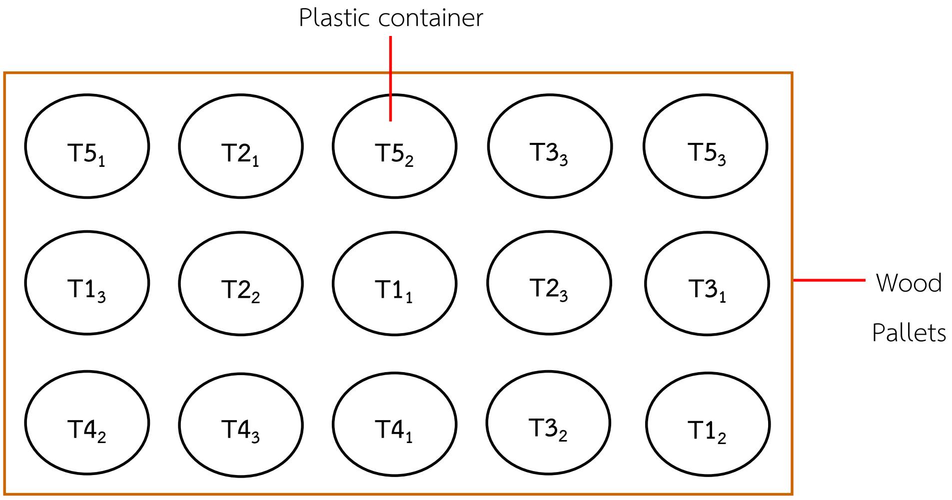


Figure 3.3 Top view of arranging container in greenhouse; $T1_1$, $T1_2$, $T1_3$: replicate 1 to 3 of treatment 1, $T2_1$, $T2_2$, $T2_3$: replicate 1 to 3 of treatment 2, $T3_1$, $T3_2$, $T3_3$: replicate 1 to 3 of treatment 3, $T4_1$, $T4_2$, $T4_3$: replicate 1 to 3 of treatment 4 and $T5_1$, $T5_2$, $T5_3$: replicate 1 to 3 of treatment 5

3.3. Sampling

All vermicomposting samples are collected on day 15, 30, 45, and 60. The samples are mixed and then picked out with sieve to separate the earthworms. Afterwards, the samples without earthworms are air dried overnight and placed on top of stainless-steel sieves in size of 2 mm and 0.5 mm. The air-dried samples will be physical-chemical analyzed.

3.4. Physical-chemical analysis

The vermicompost's physical and chemical characteristics will be tested according to the operation manual for analyzing plants, fertilizers, and soil improvement (Land Development Department, Thailand, 2010), as shown in Table 3.1

3.5. Seed germination test

The phytotoxicity of the final vermicompost is assessed with a seed germination test using aqueous extracts from vermicomposts. Samples of each treatments (15 replicates) are mixed with distilled water at a ratio of 1:5 (w/w) and are shaken for 1 hours, then filtered by 0.22-μm-filter membrane. The 2 mL extract is dropped onto a 90 mm diameter sterilized filter paper in a sterile Petri dish; 20 maize seeds are also put into this dish. The seeds are incubated at 25 °C under dark conditions for 48 hours. As a control, the test is done using the same method with deionized water instead of extract from vermicompost. After 48 hours, the number of seeds in each dish is determined (Zhang & Sun, 2017).

The percentage of seed germination (SG) was calculated with the following formula (Luo et al., 2018):

$$\%\mathrm{SG} = \frac{\text{Number of germinated seeds}}{\text{Number of total seeds}} \times \mathbf{100\%}$$

The vermicomposting processes are shown in Figure 3.4

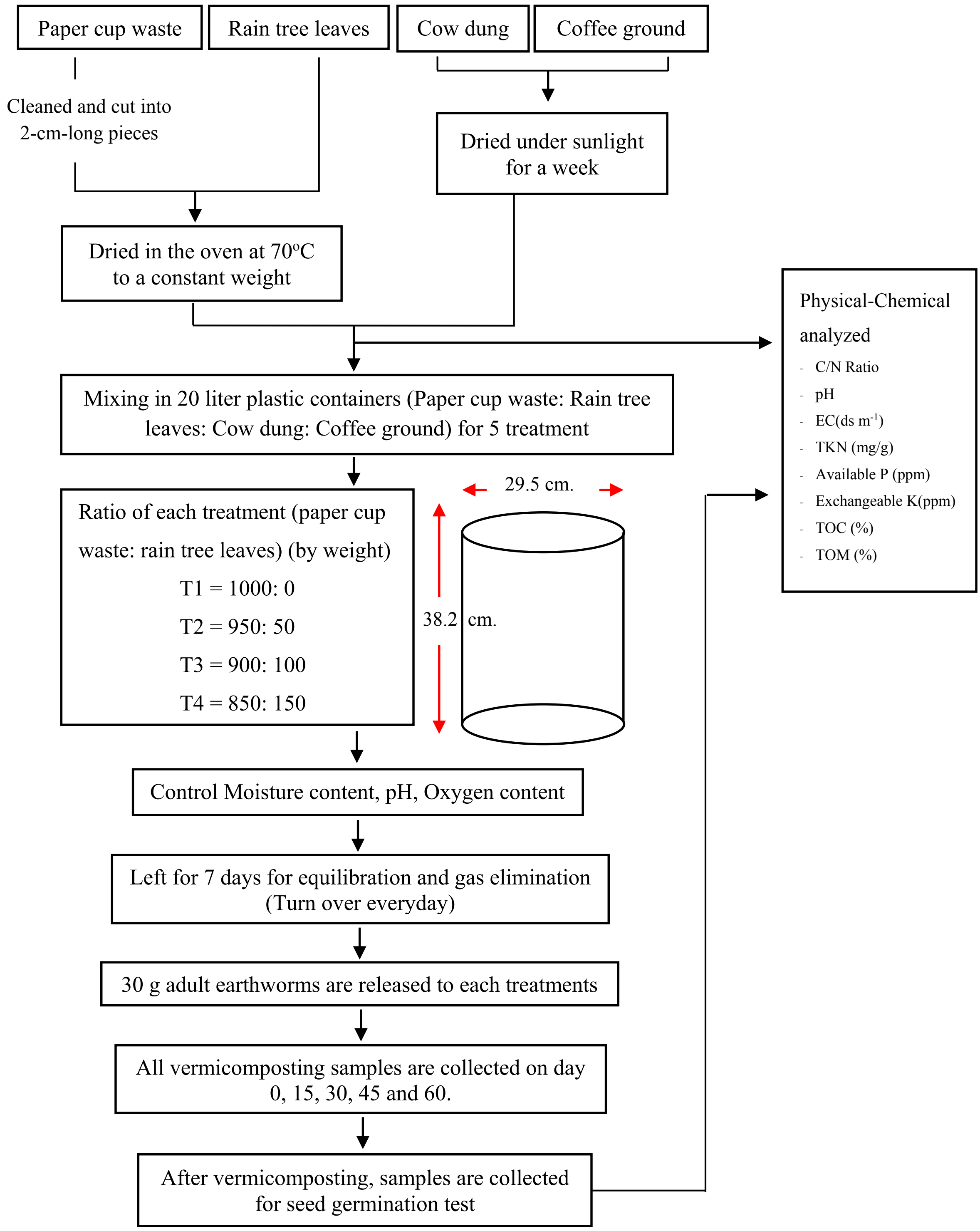


Figure 3.4 Flowchart of the vermicomposting processes

3.6. Statistical analysis

The data were analyzed using a one-way analysis of variance (ANOVA) followed by Duncan's Multiple Range Tests (DMRT) for the comparison of the means at the significance level at 0.05.

Chapter 4
Results and discussion

4.1 Chemical properties of raw material

Based on the chemical analysis of the raw material before vermicomposting, as shown in Table 4.1, the paper cup waste has the highest carbon-to-nitrogen ratio of 1,763.74, indicating that it is a slowly degraded material. Therefore, the used of paper cup waste as the raw material for vermicomposting is necessary to use other raw materials together in order to produce faster degradation with the initial carbon-to-nitrogen value of 25:1 which is suitable for composting (Kongrod, 2003). Coffee ground, rain tree leaves, and cow dung have the lower in carbon-to-nitrogen ratio, respectively. Rain tree leaves have the highest amount of total kjeldahl nitrogen, total organic carbon, and total organic matter is 2.62±0.066, 45.54±1.72 and 78.33±2.96, respectively. Cow dung has the most amount of available phosphorus and exchangeable potassium is 2,854.99±143.97 and 27,465.68±1,714.87 ppm, respectively. As shown in Table 4.1

Table 4.1 Chemical properties of raw materials used for vermicomposting.

Parameters	Raw materials			
	Paper Cup Waste (PCW)	**Rain Tree Leaves (RTL)**	**Cow dung (CD)**	**Coffee Ground (CG)**
C/N Ratio	1763.74	17.39	15.37	17.58
%TKN[1]	0.0213±0.00074	2.62±0.066	1.38±0.038	1.81±0.011
Available P (ppm)	201.51±33.10	376.65±70.19	2,854.99 ±143.97	410.55±23.52
Exchangeable K (ppm)	12.003 ±2.66	6,385.81 ±916.26	27,465.68 ±1,714.87	3,777.78 ±173.61
%TOC	37.49±0.71	45.54±1.72	21.28±1.58	31.82±0.56
%TOM	64.49±1.22	78.33±2.96	36.60±2.72	54.73±0.97

[1] Total Kjeldahl nitrogen (TKN) content of raw materials is calculated by
Land Development Department, 2010

4.2 Physical characteristics of raw materials during vermicomposting

The physical characteristics of the raw material during vermicomposting of all treatment from the observed at the initial vermicomposting on day 0 into day 30, the vermicompost had heterogeneous because it could be separated into pieces of raw materials used in vermicomposting, those raw materials are paper cup waste and rain tree leaves. But, when vermicomposted in day 45 to day 60, the texture of vermicompost is homogeneous, which cannot be separated as raw materials. So, The texture of T1 to T5 within 60 days were similar to organic matter which was dark brown color, as shown in Figure 4.1

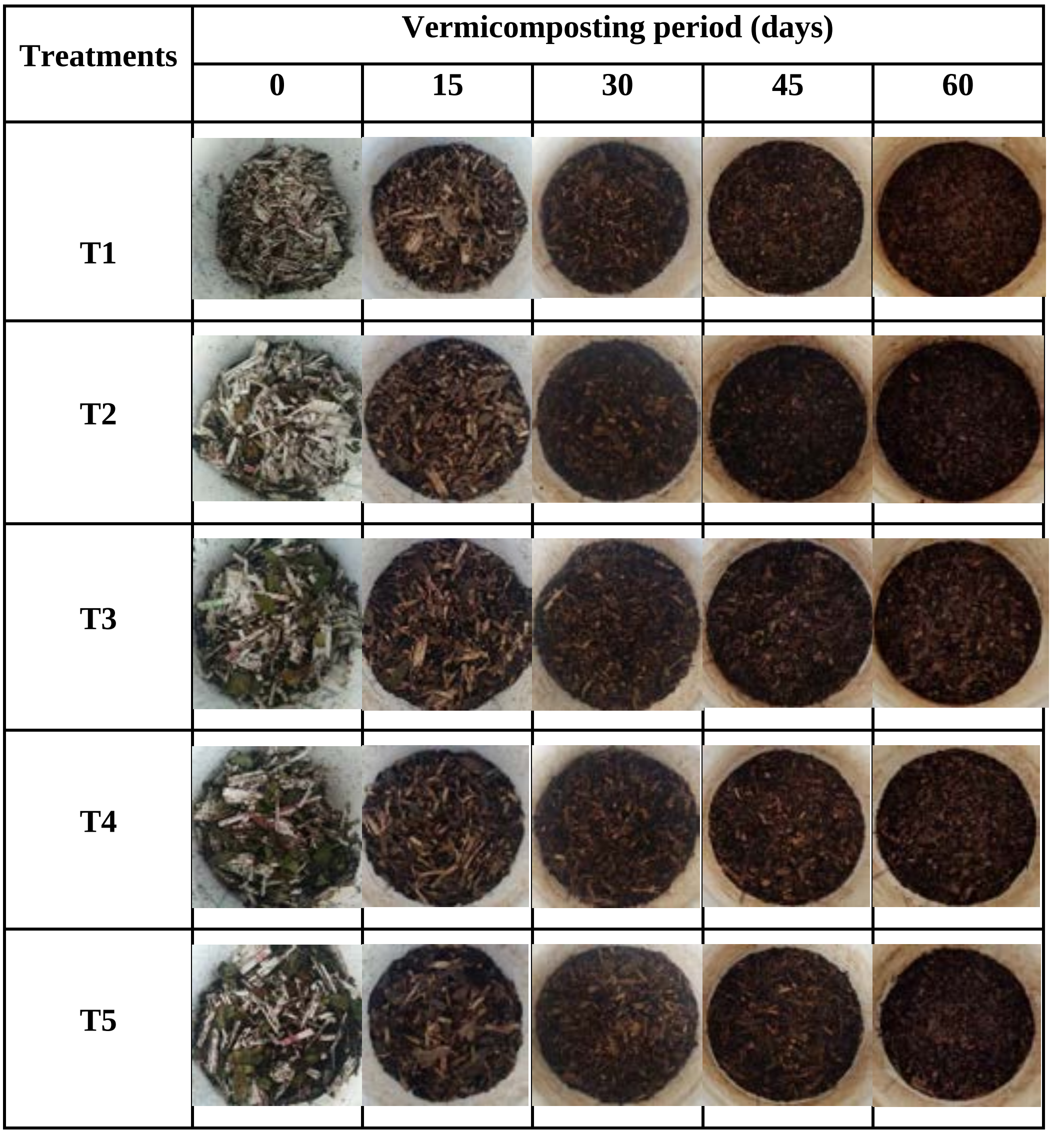


Figure 4.1 Physical characteristic of vermicompost in treatment T1 to T5 on day 0, 15, 30, 45 and 60.

4.3 Changes in temperature during vermicomposting

In the initial vermicomposting, the temperature in the vermicomposts piles increasing rapidly which were resulted from heat generated by microbial degradation activities. After that, the temperature gradually decreases until entering the phase of composting in the mesophilic phase. In this phase, mostly caused by the degradation of mesophilic bacteria which are bacteria that grow well in the temperature range 25-45 °C. Therefore, the temperature in the vermicompost pile was not over 45 °C (Jolanun, 2013) and it remained the same until the maturation of vermicomposting which is based on the theory of composting. As shown in Figure 4.2

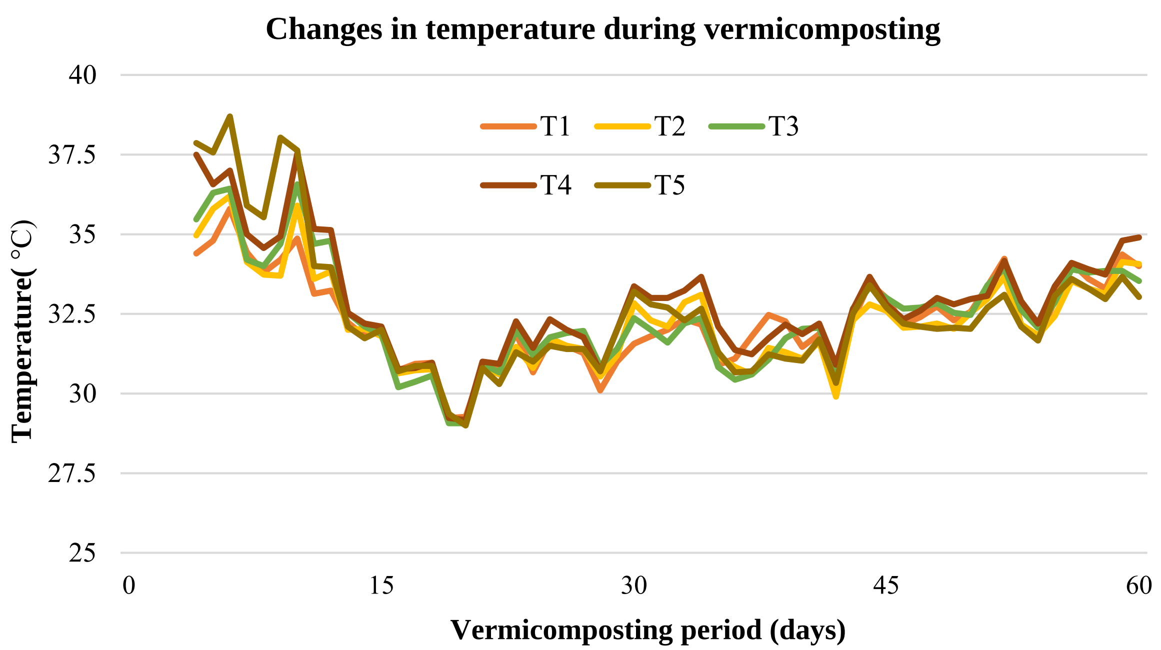


Figure 4.2 Changes in temperature during vermicomposting within 60 days

4.4 Variation of pH

The variation of pH value was affected by the organic compound decomposition during vermicomposting (kongrod, 2003). The vermicomposting pH values on day 15, 30 and 45 tend to increase in all treatments (Figure 4.3) with values in the range of 7.25-8.18 which the value that in the range (pH value is 7-9) with high degradation rate (Jolanun, 2013). The final vermicomposting pH values of all treatments were not significantly different ($p = 0.465$) (Figure 4.4) with values in the range of 8.16-8.41which defer to the compost quality standards of the Department of Agriculture (2005) by the appropriate pH value must be in the range of 5.5-8.5.

Moreover, the initial vermicomposting, the pH value maybe decreased because organic materials that are easily degraded are rapidly decomposed and produce CO_2, ammonium ions, NO_3^-, and volatile organic acids in the system which affected the lower pH values (Khatua et al., 2018; Pramanik et al., 2007). After that, the pH values increased rapidly until entering an alkaline state with values in the range of 8-9 caused by microorganisms used of organic acid generated from the decomposition process as a carbon source instead and ammonium ions increased the pH values in the system, resulting in reduced acidity (Jolanun, 2013).

In addition, the pH value higher than 8 helps to promote the degradation process and reduction forms of nitrogen compounds to become into dissolved ammonium compounds affected the pH value of the system more alkalinity. When raw materials decomposed and began to stabilized with pH value in the range of 7-8 and constant value until the final vermicomposting.

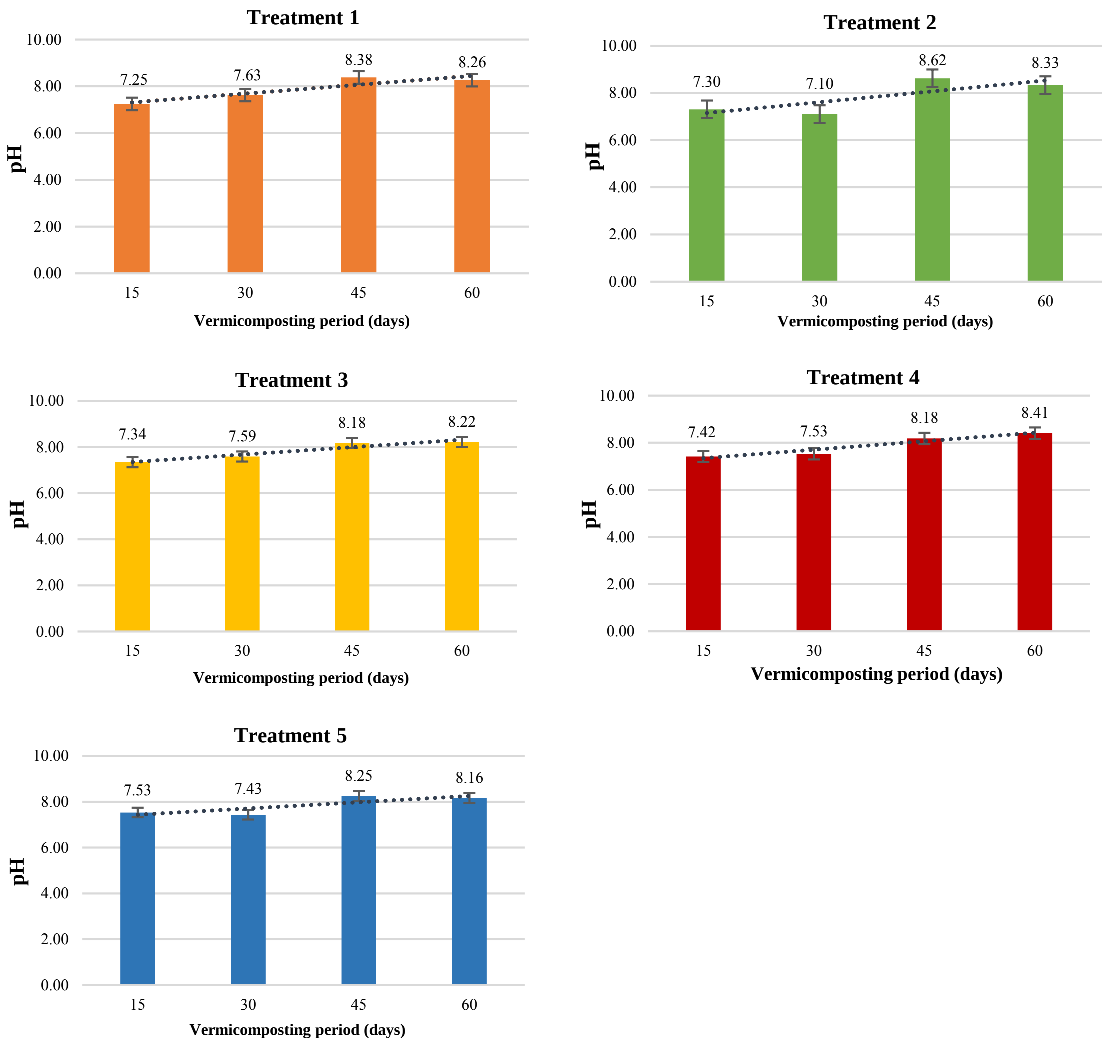


Figure 4.3 Variation of pH of treatment 1 to 5 on day 15, 30, 45 and 60

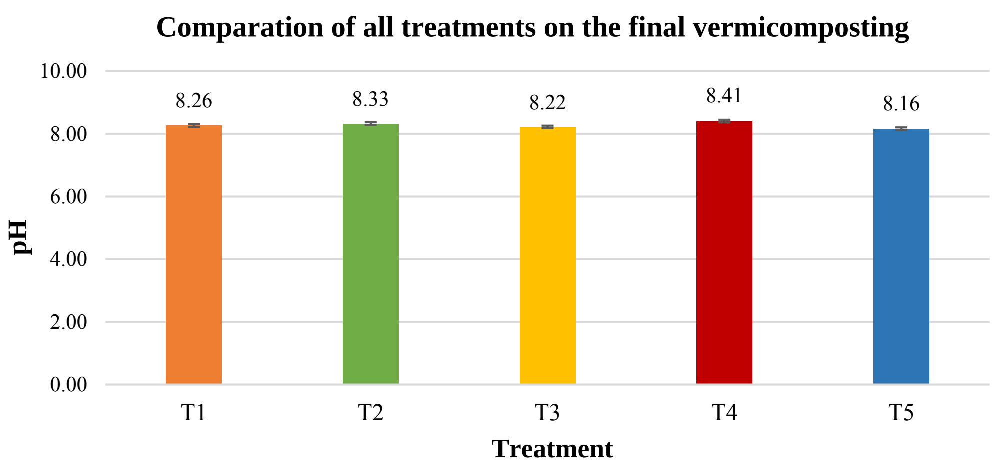
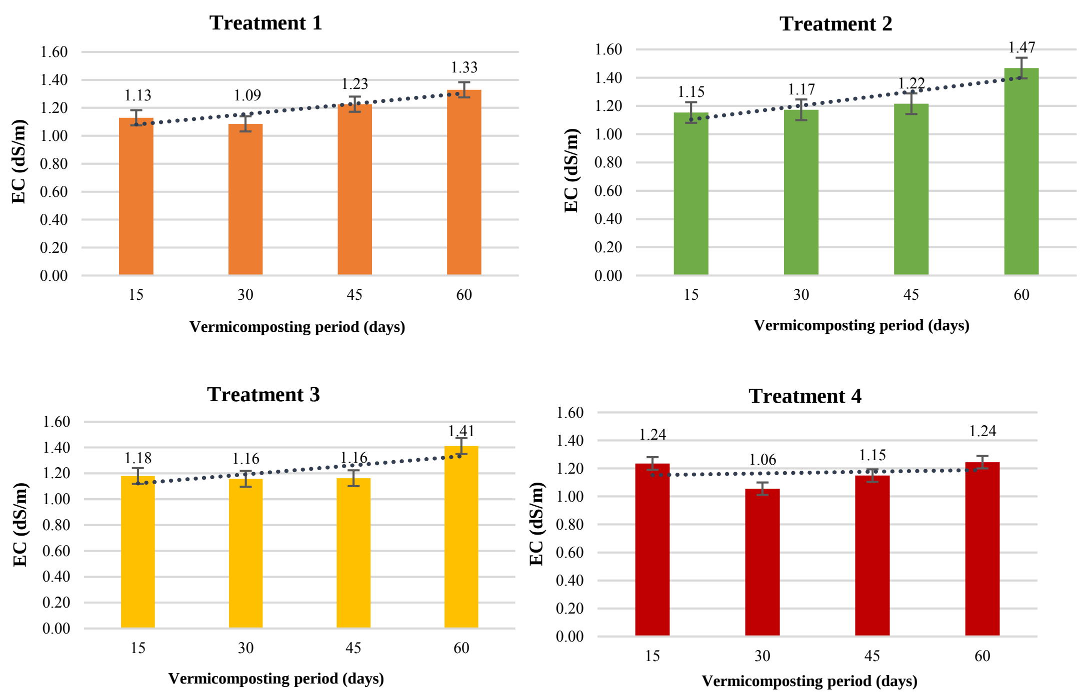


Figure 4.4 Comparation of pH value of all treatments on the final vermicomposting

4.5 Variation of electrical conductivity (EC)

The initial to final vermicomposting of EC values (on day 15, 30, 45 and 60) tends to increase in all treatments (Figure 4.5) with values in the range of 1.13-1.55 dS/m. In the final vermicomposting, the EC values of all treatments were not significantly different ($p = 0.315$) (Figure 4.6) with values in the range of 1.24-1.55 dS/m which defer to the compost quality standards of the Department of Agriculture (2005) by the appropriate EC value must not be greater than 6 dS/m provided that EC value greater than 6 dS/m affected phytotoxicity due to EC was the value of soluble salt whereas the more soluble salt affected to roots more difficult to absorb water resulted in plant causes dehydration (Panpuang et al,. 2014). The increase in EC values could be explained by the generation of minerals ions during the ingestion and excretion of earthworms and release of minerals from the decomposition of organic matter in cations form during vermicomposting (Hanc et al., 2014; Arumugam et al., 2018)



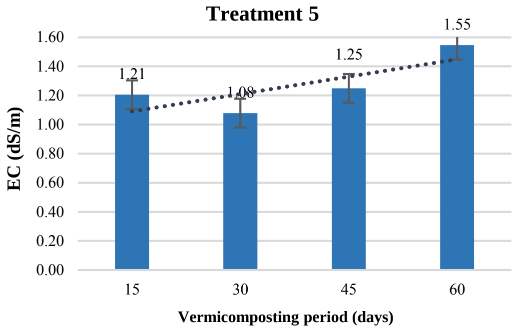


Figure 4.5 The EC values of treatment 1 to 5 on day 15, 30, 45 and 60

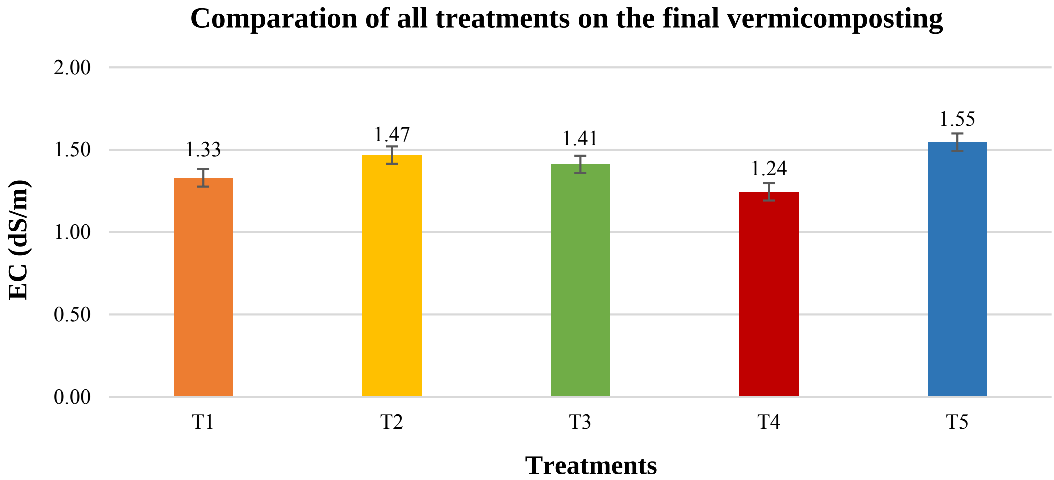


Figure 4.6 Comparation of EC value of all treatment on the final vermicomposting

4.6 Variation in Total organic carbon and Total organic matter

4.6.1 Total organic carbon

Total organic carbon content was gradually declining from initial to final vermicomposting (on day 15, 30, 45 and 60) in all treatments (Figure 4.7). In the final vermicomposting, T4 had the highest total organic carbon content of 33.47±0.56 % by weight, followed by T1 (33.16±0.25%), T5 (32.91±0.41%), T2 (32.44±0.78%) and T3 (32.09±0.61%) respectively. However, the total organic carbon content of all treatments were not significantly different ($p = 0.074$) (Figure 4.7). The reduction of total organic carbon content could be attributed to the decomposition of organic matter including carbon loss from microbial respiration and used carbon to create cell elements microbial (Panpuang et al., 2014). Moreover, Zhi-wei et al., (2019) reported that the earthworm has the ability to utilize organic waste as carbon/energy sources and convert into their biomass.

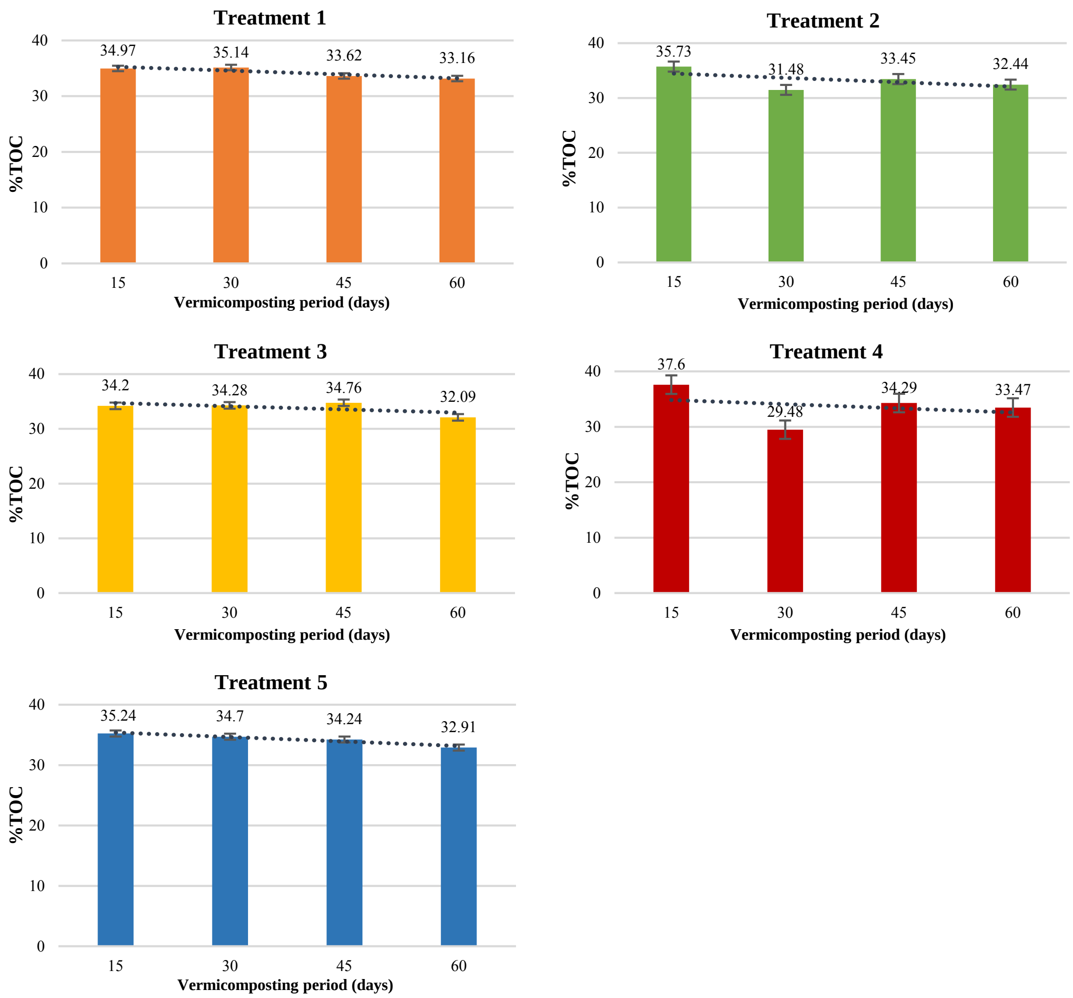


Figure 4.7 Variations of total organic carbon content in treatment 1 to 5 on day 15, 30, 45 and 60

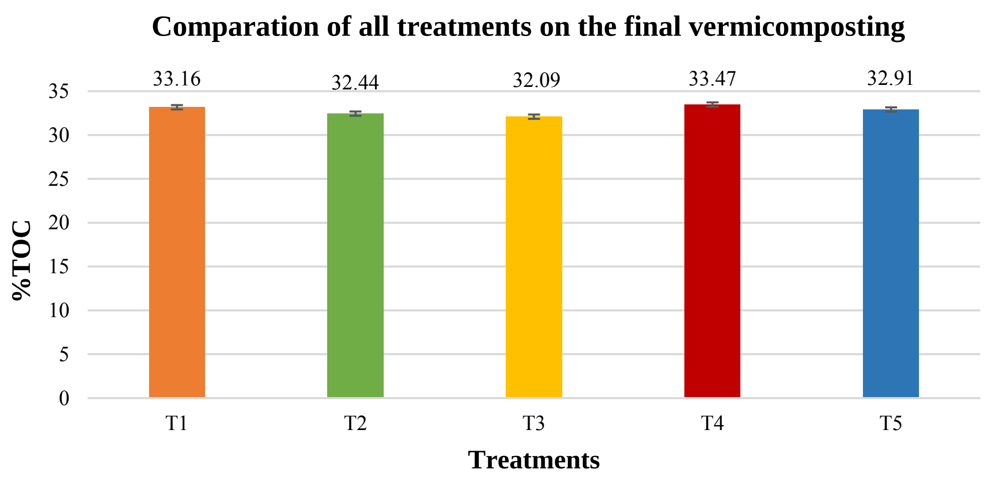
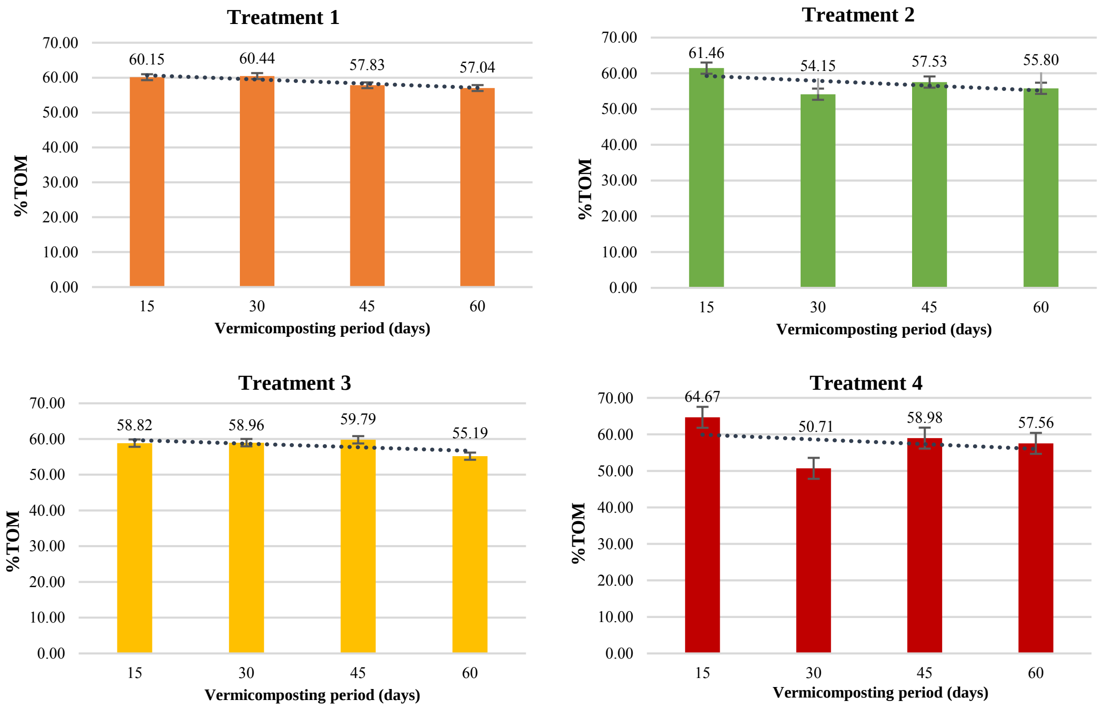


Figure 4.8 Comparation of total organic carbon content of all treatment on the final vermicomposting

4.6.2 Total organic matter

Total organic matter content was gradually declining from initial to final vermicomposting (on day 15, 30, 45 and 60) in all treatments (Figure 4.9). In the final vermicomposting, T4 had the highest total organic matter content of 57.56±0.96 % by weight, followed by T1 (57.04±0.42%), T5 (56.61±0.71%), T2 (55.79±1.35%) and T3 (55.20±1.06%) respectively, which present the same tendency compared to the total organic carbon content. However, the total organic carbon content of all treatments were not significantly different ($p = 0.074$) (Figure 4.10) which defer to the compost quality standards of the Department of Agriculture (2005) by total organic carbon content must be at least 30% by weight. The reduction of total organic matter content has the same cause as the reduction of the total organic carbon content (in section 4.6.1).



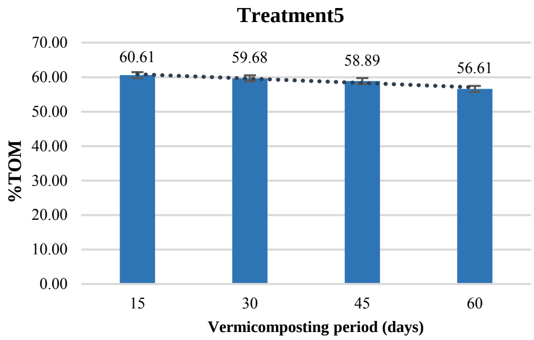


Figure 4.9 Variations of total organic matter content in treatment 1 to 5 on day 15, 30, 45 and 60

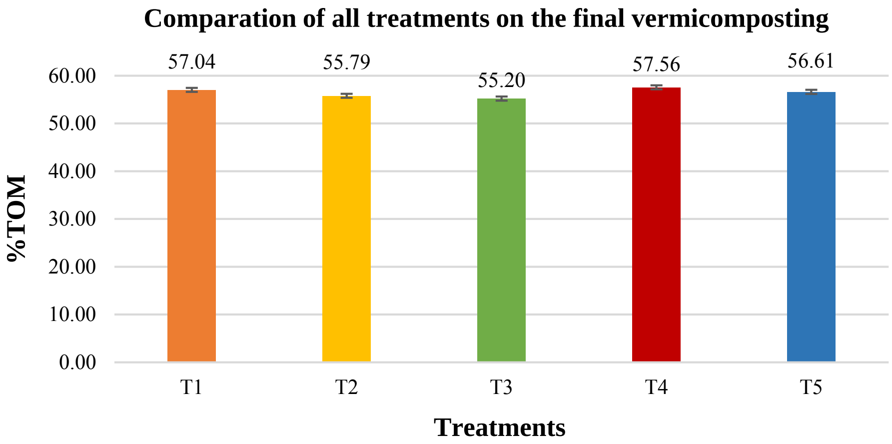


Figure 4.10 Comparation of total organic matter content of all treatment on the final vermicomposting

4.7 Variation in Total Kjeldahl nitrogen

The total Kjeldahl nitrogen content of all treatments tends to increase during the initial to final vermicomposting (on day 15, 30, 45 and 60) (Figure 4.11). In the final vermicomposting, total nitrogen content of all treatments were significantly different ($p = 0.030$) (Figure 4.12). T4 had the highest total Kjeldahl nitrogen content of 14.17±0.46%, followed by T3 (13.59±0.82%), T5 (13.52±0.32%), T2 (13.23±0.82%) and T1 (12.24±0.48%) respectively. However, total nitrogen content of all treatments defer to the compost quality standards of the Department of Agriculture (2005) by total nitrogen content must be at least 1.0 % by weight. Negi et al., (2018) presented that the increase in total Kjeldahl nitrogen content was caused by nitrogen immobilization in compost. Also, the mineralization of organic nitrogen through ammonification, ammonium volatilization and CO_2 emission increased nitrogen contents in the final vermicompost.

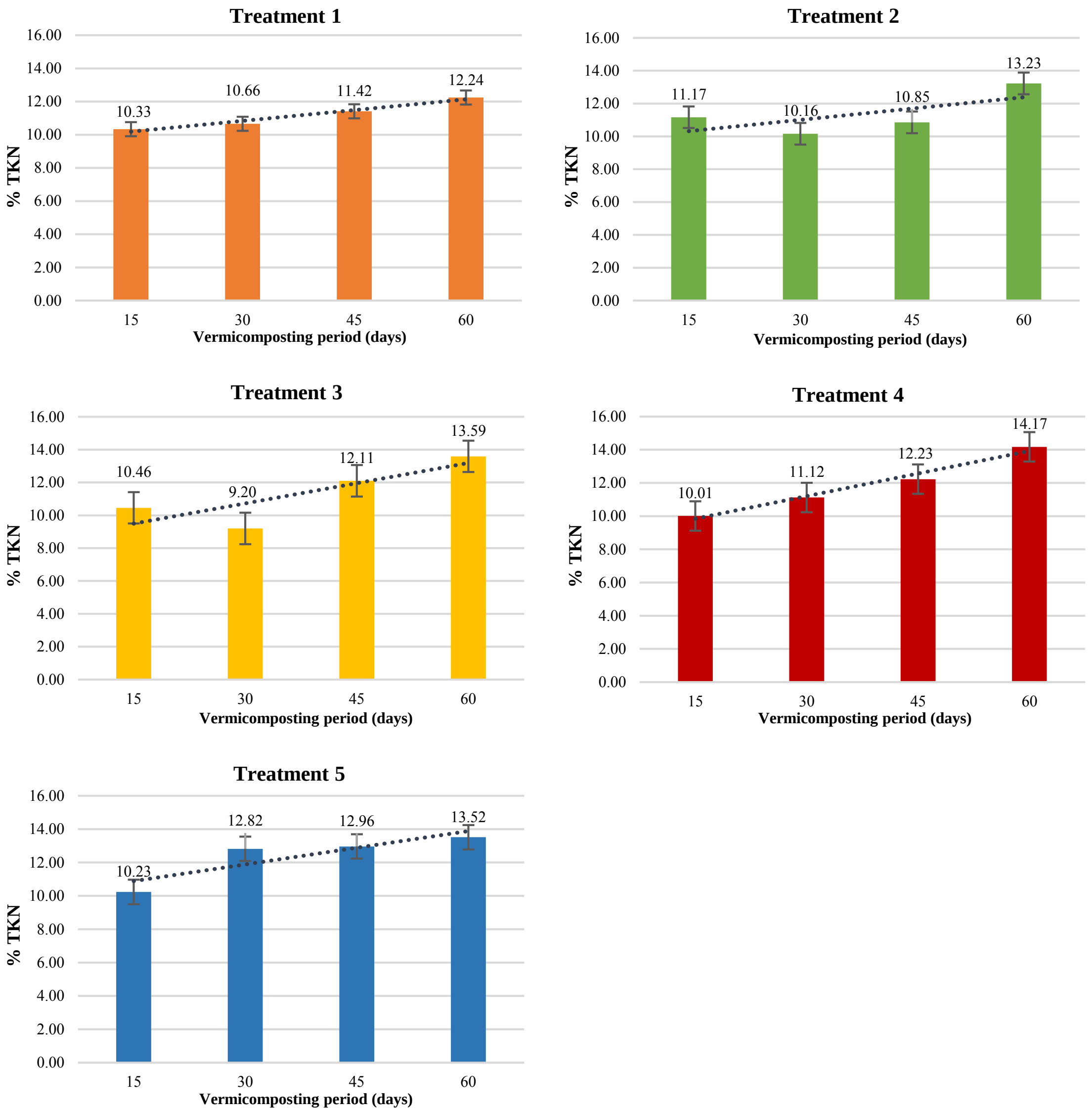


Figure 4.11 Variations of total Kjeldahl nitrogen content in treatment 1 to 5 on day 15, 30, 45 and 60

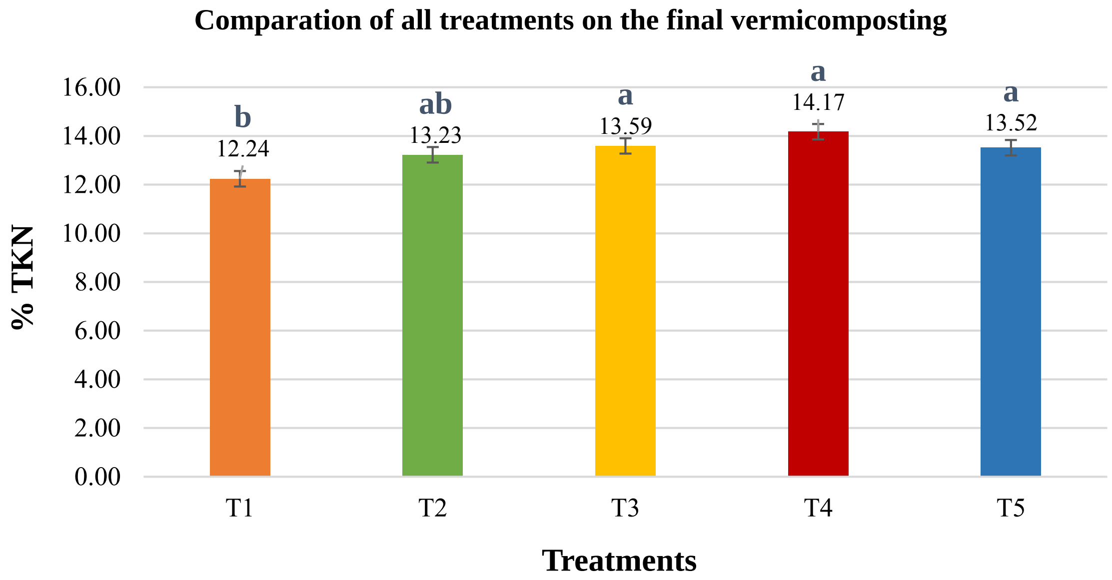


Figure 4.12 Comparation of total Kjeldahl nitrogen content of all treatment on the final vermicomposting

4.8 Variation in available phosphorus

The available phosphorus content of T1 to T3 tends to increase slightly from the initial to final vermicomposting (on day 15, 30, 45 and 60) but T4 and T5 tend to rise and fall (Figure 4.13). In the final vermicomposting, available phosphorus content of all treatments were significantly different ($p = 0.001$) (Figure 4.14). T1 had the highest available phosphorus content of 1,418.08±305.45 ppm, followed by T3 (728.81±257.48 ppm), T4 (589.45±81.55 ppm), T2 (502.83±114.26 ppm) and T5 (472.69±57.98 ppm) respectively. The available phosphorus content in all treatments did not compliant with the standards of the Department of Agriculture (2005) by determined that the value must be at least 0.5% by weight or 5,000 ppm.

The increase in available P can be described from the activity of microbes and earthworms. When microorganisms decompose organic matter, produce acid which important mechanism for solubilization of insoluble phosphorus (Pramanik et al., 2007). Organic acids that are important to phosphorus solubilization are carbonic, nitric, and sulfuric (Hanc et al., 2014). The microflora in the gut and cast of earthworms along with secreted mucus plays an important role in increasing phosphorus content in vermicomposting (Khatua et al., 2018). Furthermore, all treatments have mixed cow dung which based on analysis of chemical properties it was found that the available phosphorus content of 2,854.99±143.97 ppm (Table 4.1), it is possible that the increase available phosphorus in vermicompost this cause as well (Arumugam et al., 2018). The reduction of available phosphorus content caused by the used of phosphorus as an energy source by microorganisms (Iwai et al., 2016).

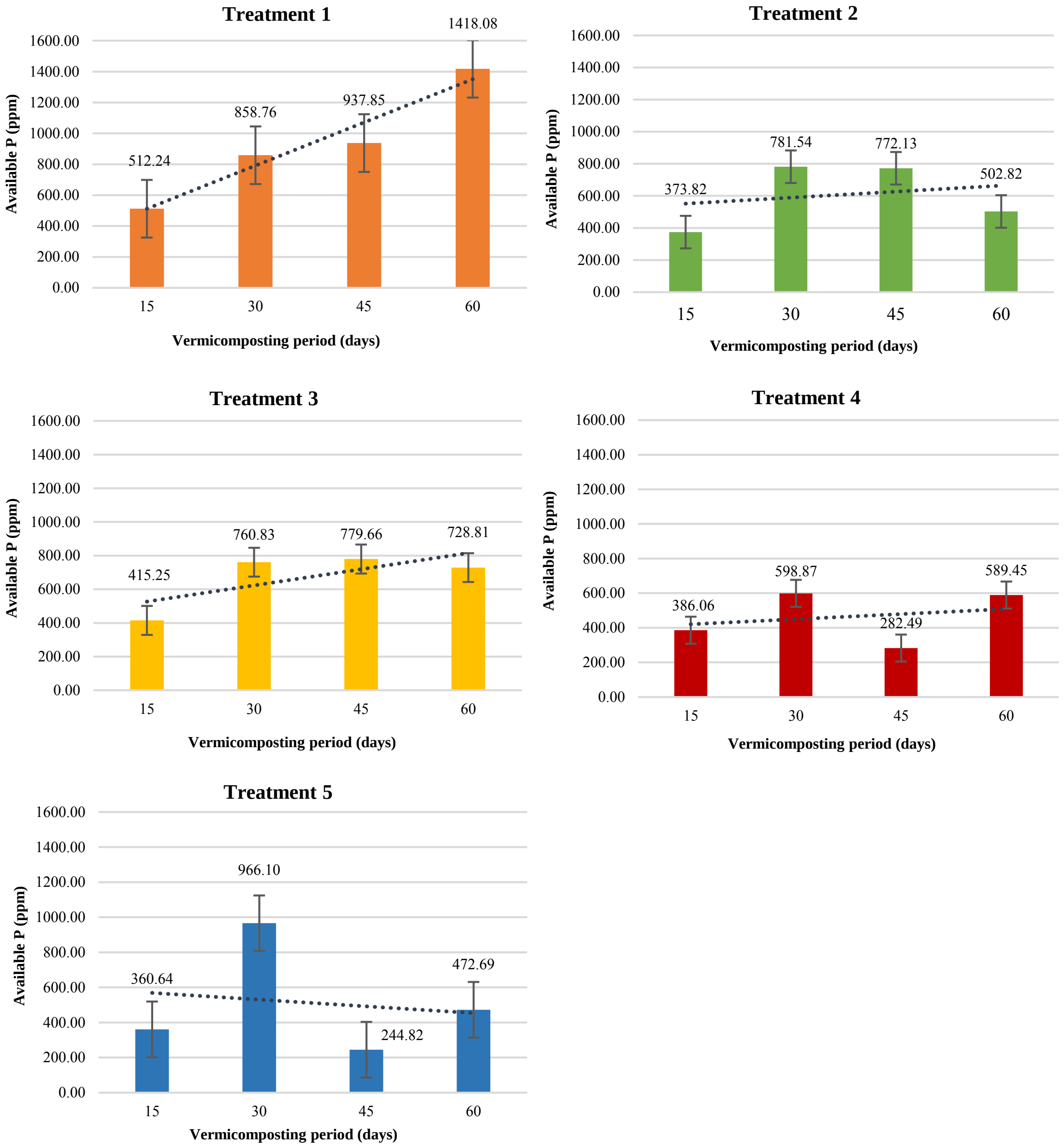


Figure 4.13 Variations of available phosphorus content in treatment 1 to 5 on day 15, 30, 45 and 60

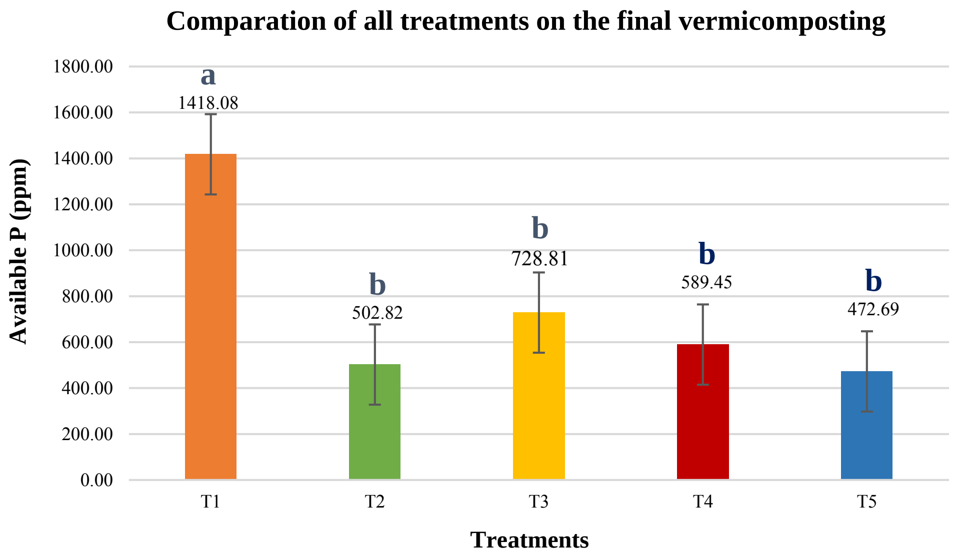


Figure 4.14 Comparation of available phosphorus content of all treatment on the final vermicomposting

4.9 Variation in Exchangeable potassium

The exchangeable potassium content of T1 tends to increase gradually from the initial to final vermicomposting (on day 15, 30, 45 and 60) but T2 to T5 tend to decrease slightly (Figure 4.15). In the final vermicomposting, exchangeable potassium content of all treatments were significantly different ($p = 0.000$) (Figure 4.16). T1 had the highest exchangeable potassium content of 8,146.81±739.40 ppm, followed by T5 (5,505.15±360.32 ppm), T4 (4,089.58±385.16 ppm), T2 (4,143.41±384.22 ppm) and T3 (3,861.98±1,024.56 ppm) respectively. The exchangeable potassium content in T1 and T5 defer with the standards of the Department of Agriculture (2005) by determined that the value must be at least 0.5% by weight or 5,000 ppm. Khatua et al., (2018) reported that the microflora in the gut and cast of earthworms along with secreted mucus plays an important role in increasing potassium content in vermicomposting as well as increasing the potassium content.

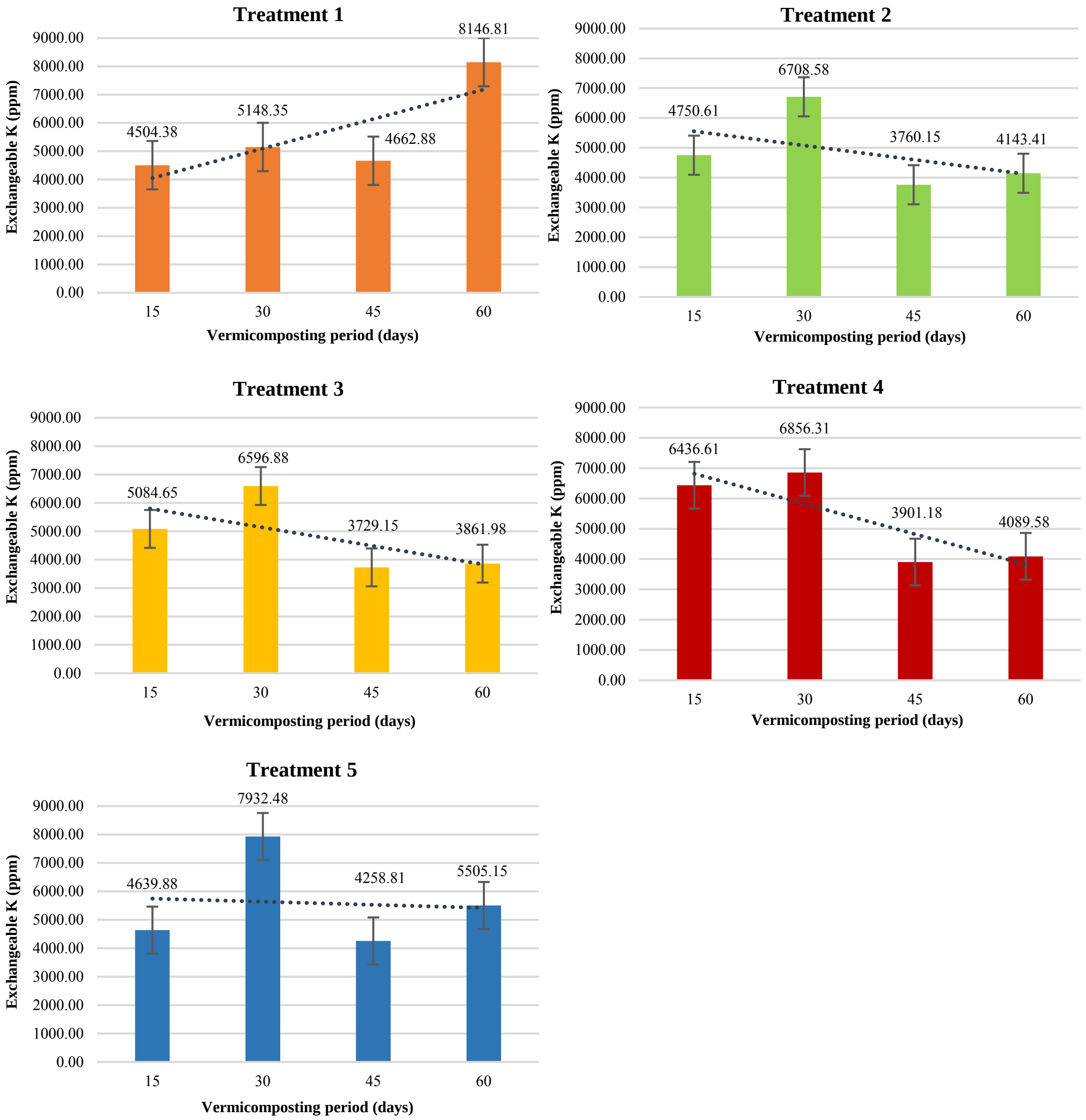


Figure 4.15 Variations of exchangeable potassium content in treatment 1 to 5 on day 15, 30, 45 and 60

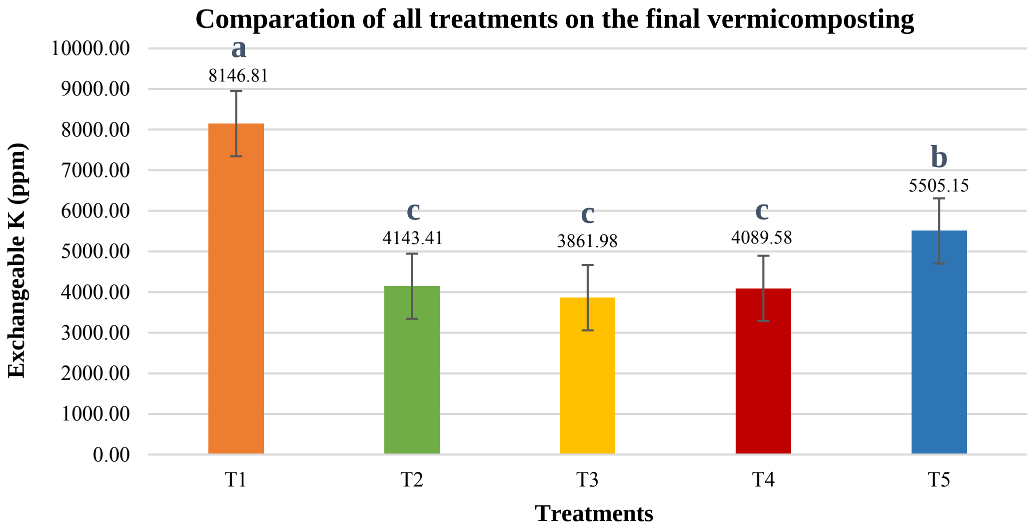
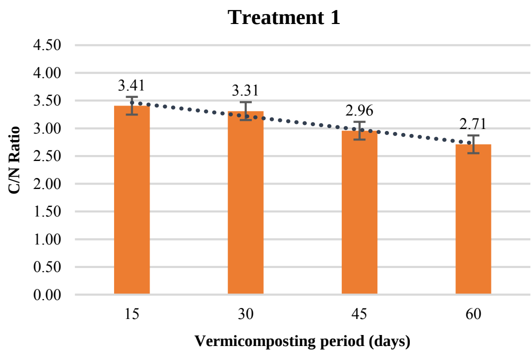
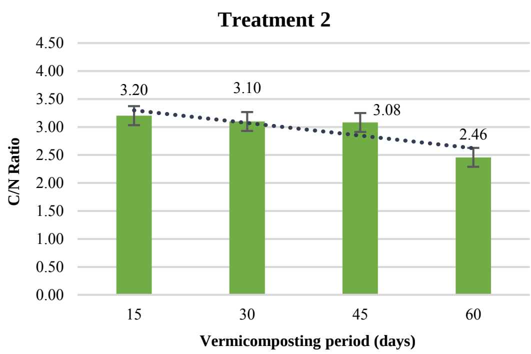


Figure 4.16 Comparation of exchangeable potassium content of all treatment on the final vermicomposting

4.10 Variation in C/N ratio

The C/N ratio of all treatment tends to decrease gradually from the initial to final vermicomposting (on day 15, 30, 45 and 60) (Figure 4.17) with values in the range of 2.36-3.44. In the final vermicomposting, T1 had the highest of C/N ratio of 2.71% because T1 was the ratio with the most amount of paper cup waste. From the chemical properties analysis of paper cup waste found that the initial high C/N ratio affected the final vermicomposting was a high C/N ratio. Followed by T2 (2.46), T5 (2.44), T3 (2.37), and T4 (2.36), respectively. However, the C/N ratio of all treatments were not significantly different ($p = 0.051$) (Figure 4.18) which defer to the compost quality standards of the Department of Agriculture (2005) by the appropriate C/N ratio must not be greater than 20:1.





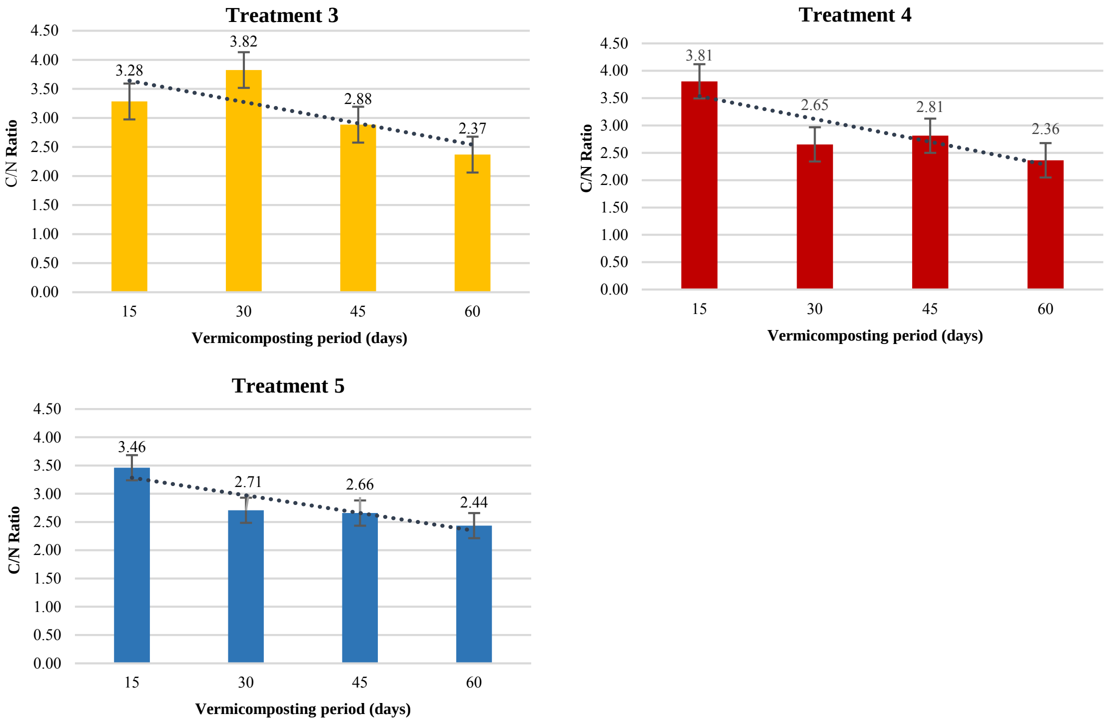


Figure 4.17 Variations of C/N ratio in treatment 1 to 5 on day 15, 30, 45 and 60

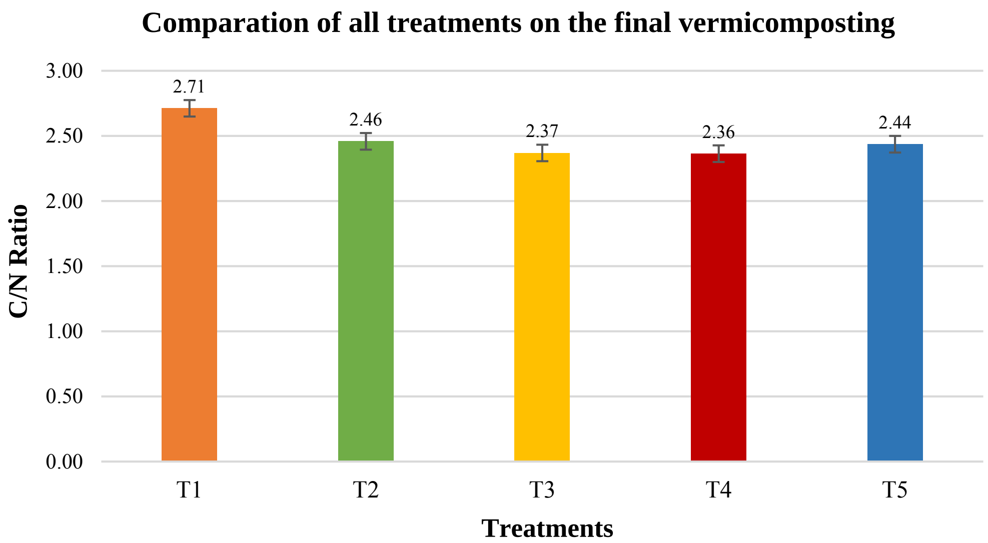


Figure 4.18 Comparation of C/N ratio of all treatment on the final vermicomposting

4.11 The phytotoxicity of vermicomposts

4.11.1 Seed germination test

From the study of the seed germination test as the biological parameters used to assess phytotoxicity, it was found that the T1 had the highest percent of seed germination of 45.00±10.00%, followed by T3 (41.67±24.66%), T4 (35.00±22.91%), T5 (33.33±24.66%) and T2 (31.67±23.63%), respectively. However, percent of seed germination of all treatments were not significantly different (p = 0.930). As shown in Table 4.2

Table 4.2 Seed germination (SG) of maize seeds of different vermicomposts.

Treatments	SG (%)
Blank	15.00
T1	45.00
T2	31.67
T3	41.67
T4	35.00
T5	33.33

Chapter 5
Conclusions

This study focuses on the utilization of organic waste at Chulalongkorn University as a raw material for vermicomposting. The objectives of this study were to investigate the appropriate ratio of paper cup waste and rain tree leaves in vermicomposting. There were 5 treatments (T1 to T5), which in each treatment using paper cup waste and rain tree leaves in different ratios mixed with cow dung and coffee ground as bulking agent. The result of physical and chemical properties analysis of all treatment on the final vermicomposting found that T1 to T5 within 60 days, the vermicomposting process can be used to decompose waste from paper cups and rain tree leaves.

For physical properties, the textures of vermicomposts of all treatments were similar to organic matter, dark brown color and the EC values were not significantly different ($p \geq 0.05$). Chemical properties, the values of pH, total organic carbon, total organic matter, and C/N ratio were not significantly different ($p \geq 0.05$) while the primary macronutrients (total Kjeldahl nitrogen, available phosphorus, and exchangeable potassium) were significantly different ($p \leq 0.05$).

The comparison with the compost quality standards of the Department of Agriculture (2005) presented that T1 to T5 can help improve the physical properties of the soil but required to increase the nutrients (nitrogen, phosphorus and potassium) that should be used along with chemical fertilizers. Considering the economic value, it was found that the most suitable ratio used to vermicomposting is T2 to T5. Because of the ratio of these treatments are rain tree leaves as raw materials for vermicomposting which rain tree leaves contain the primary macronutrients nitrogen, phosphorus and potassium as the main component. Thus, the amount of chemical fertilizer required to adjust the carbon-to-nitrogen ratio before vermicomposting is reduced and more cost savings in vermicomposting.

Consequently, the utilization of organic wastes to vermicomposting can be one of the alternative ways to manage waste at Chulalongkorn University. That helps to recycle waste and reduce waste disposal costs.

Further studies to enhance the amount of primary macronutrients (total Kjeldahl nitrogen, available phosphorus, and exchangeable potassium) so that it can be used to improve the chemical properties of the soil should be conducted and life cycle assessment and economic feasibility should be examined in terms of sustainable development.

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Appendix A

A. Monitoring and measuring the temperature in the vermicompost pile for a period of 60 days

Table A.1 Results of temperature

Vermicomposting period (days)	Treatments (T)				
	T1	T2	T3	T4	T5
0					
1					
2					
3					
4	34.4	35.0	35.5	37.5	37.9
5	34.8	35.8	36.3	36.6	37.6
6	35.8	36.2	36.4	37.0	38.7
7	34.4	34.1	34.2	35.0	35.9
8	33.8	33.7	34.0	34.6	35.5
9	34.2	33.7	34.7	34.9	38.0
10	34.9	35.9	36.6	37.5	37.6
11	33.1	33.6	34.7	35.2	34.0
12	33.2	33.8	34.8	35.1	34.0
13	32.2	32.0	32.5	32.5	32.1
14	31.8	32.0	32.1	32.2	31.7
15	32.1	31.8	31.9	32.1	32.0
16	30.7	30.6	30.2	30.8	30.7
17	30.9	30.7	30.4	30.8	30.9
18	31.0	30.8	30.6	31.0	30.9
19	29.2	29.1	29.1	29.2	29.4
20	29.3	29.1	29.1	29.2	29.0
21	30.8	30.9	30.9	31.0	30.8
22	30.8	30.6	30.7	30.9	30.3
23	31.9	31.5	32.0	32.3	31.3
24	30.7	30.8	31.2	31.4	31.0
25	31.7	31.7	31.8	32.3	31.5
26	31.5	31.5	31.9	32.0	31.4
27	31.3	31.4	32.0	31.8	31.4
28	30.1	30.5	30.9	30.7	30.7
29	31.0	31.2	31.4	32.0	32.0
30	31.6	32.8	32.4	33.4	33.2
31	31.8	32.3	32.0	33.0	32.8
32	32.0	32.1	31.6	33.0	32.7
33	32.3	32.9	32.2	33.2	32.3
34	32.2	33.1	32.4	33.7	32.7
35	30.9	31.2	30.8	32.1	31.3
36	31.1	30.8	30.4	31.4	30.7
37	31.8	30.6	30.6	31.2	30.7
38	32.5	31.4	31.1	31.7	31.2
39	32.3	31.3	31.7	32.2	31.1
40	31.5	31.1	32.0	31.9	31.0
41	31.9	31.6	32.1	32.2	31.7
42	30.2	29.9	30.4	30.9	30.3
43	32.3	32.3	32.7	32.6	32.5
44	33.5	32.8	33.3	33.7	33.4
45	33.0	32.6	33.0	32.8	32.7
46	32.2	32.1	32.7	32.3	32.2
47	32.4	32.1	32.7	32.6	32.1
48	32.7	32.2	32.8	33.0	32.0
49	32.3	32.0	32.5	32.8	32.1
50	32.6	32.5	32.5	33.0	32.0
51	33.4	33.0	33.4	33.1	32.7
52	34.2	33.7	33.9	34.2	33.1
53	32.1	32.2	32.6	32.9	32.1
54	31.7	31.8	32.1	32.2	31.7
55	32.9	32.4	32.9	33.4	33.1
56	34.1	33.5	33.9	34.1	33.6
57	33.6	33.3	33.8	33.9	33.3
58	33.3	33.1	33.9	33.7	33.0
59	34.4	34.1	33.9	34.8	33.7
60	34.0	34.1	33.5	34.9	33.0

Appendix B

B. Physical and chemical properties of vermicomposts on day 15, 30, 45 and 60

Table B.1 Results of the pH values

Vermicomposting period (days)	Treatments (T)				
	T1	**T2**	**T3**	**T4**	**T5**
15	7.28	7.33	7.29	7.46	7.55
	7.22	7.26	7.42	7.39	7.51
	7.24	7.32	7.32	7.40	7.53
Mean	**7.25d**	**7.30cd**	**7.34bc**	**7.42b**	**7.53a**
SD	**0.03**	**0.04**	**0.07**	**0.04**	**0.02**
30	7.68	6.93	7.59	7.74	7.82
	7.52	6.92	7.68	7.14	7.29
	7.68	7.46	7.50	7.72	7.19
Mean	**7.63**	**7.10**	**7.59**	**7.53**	**7.43**
SD	**0.09**	**0.31**	**0.09**	**0.34**	**0.34**
45	8.47	8.58	7.59	7.81	7.82
	8.57	8.65	8.38	8.4	8.48
	8.10	8.63	8.56	8.33	8.44
Mean	**8.38**	**8.62**	**8.18**	**8.18**	**8.25**
SD	**0.25**	**0.04**	**0.52**	**0.32**	**0.37**
60	8.32	8.15	8.45	8.30	8.26
	8.41	8.56	8.15	8.49	8.16
	8.06	8.27	8.06	8.43	8.07
Mean	**8.26**	**8.33**	**8.22**	**8.41**	**8.16**
SD	**0.18**	**0.21**	**0.20**	**0.10**	**0.10**

***** Different letters are significantly different among treatments ($p<0.05$ by DMRT)

Table B.2 Results of electrical conductivity values (dS/m)

Vermicomposting period (days)	Treatments (T)				
	T1	**T2**	**T3**	**T4**	**T5**
15	1.09	1.14	1.18	1.21	1.15
	1.12	1.18	1.17	1.30	1.24
	1.17	1.14	1.19	1.21	1.22
Mean	**1.13c**	**1.15bc**	**1.18abc**	**1.24a**	**1.21ab**
SD	**0.041**	**0.019**	**0.007**	**0.053**	**0.047**
30	1.08	1.19	1.11	1.02	0.96
	1.09	1.26	1.06	1.18	1.08
	1.09	1.07	1.30	0.96	1.19
Mean	**1.09**	**1.17**	**1.16**	**1.06**	**1.08**
SD	**0.006**	**0.096**	**0.13**	**0.12**	**0.11**
45	1.34	1.22	1.05	1.05	1.23
	1.22	1.27	1.20	1.20	1.27
	1.12	1.15	1.23	1.20	1.25
Mean	**1.23**	**1.22**	**1.16**	**1.15**	**1.25**
SD	**0.11**	**0.062**	**0.098**	**0.084**	**0.019**
60	1.41	1.58	1.23	1.15	1.44
	1.42	1.28	1.26	1.26	1.61
	1.16	1.54	1.75	1.33	1.59
Mean	**1.33**	**1.47**	**1.41**	**1.24**	**1.55**
SD	**0.15**	**0.16**	**0.29**	**0.089**	**0.089**

***** Different letters are significantly different among treatments ($p<0.05$ by DMRT)

Table B.3 Results of total organic carbon content (%)

Vermicomposting period (days)	**Treatments (T)**				
	T1	**T2**	**T3**	**T4**	**T5**
15	36.51	33.82	34.47	38.06	34.86
	33.64	36.31	34.21	38.29	35.88
	34.76	37.06	33.92	36.45	34.99
Mean	**34.97b**	**35.73ab**	**34.20b**	**37.60a**	**35.24b**
SD	**1.45**	**1.70**	**0.28**	**1.01**	**0.55**
30	35.52	26.64	34.70	20.93	34.58
	35.01	33.18	34.62	34.71	34.58
	34.90	34.62	33.51	32.80	34.94
Mean	**35.14**	**31.48**	**34.28**	**29.48**	**34.70**
SD	**0.33**	**4.25**	**0.67**	**7.47**	**0.21**
45	34.11	33.56	35.06	34.29	34.68
	33.87	33.22	34.96	34.67	33.09
	32.89	33.56	34.26	33.90	34.94
Mean	**33.62**	**33.45**	**34.76**	**34.29**	**34.24**
SD	**0.65**	**0.20**	**0.44**	**0.39**	**1.00**
60	32.90	31.60	32.79	34.11	33.24
	33.39	32.56	31.86	33.08	33.05
	33.20	33.15	31.63	33.21	32.45
Mean	**33.16**	**32.44**	**32.09**	**33.47**	**32.91**
SD	**0.25**	**0.78**	**0.61**	**0.56**	**0.41**

***** Different letters are significantly different among treatments ($p<0.05$ by DMRT)

Table B.4 Results of total organic matter content (%)

Vermicomposting period (days)	Treatments (T)				
	T1	**T2**	**T3**	**T4**	**T5**
15	62.79	58.16	59.29	65.46	59.96
	57.85	62.45	58.85	65.86	61.71
	59.79	63.74	58.34	62.69	60.19
Mean	**60.14b**	**61.45ab**	**58.83b**	**64.67a**	**60.62b**
SD	**2.49**	**2.92**	**0.48**	**1.73**	**0.95**
30	61.09	45.82	59.68	36.00	59.48
	60.22	57.07	59.55	59.70	59.48
	60.03	59.55	57.64	56.42	60.10
Mean	**60.45**	**54.15**	**58.96**	**50.71**	**59.68**
SD	**0.57**	**7.32**	**1.14**	**12.84**	**0.36**
45	58.67	57.72	60.30	58.98	59.65
	58.26	57.14	60.13	59.63	56.91
	56.57	57.72	58.93	58.31	60.10
Mean	**57.83**	**57.53**	**59.79**	**58.97**	**58.89**
SD	**1.11**	**0.34**	**0.75**	**0.66**	**1.72**
60	56.59	54.35	56.40	58.67	57.17
	57.43	56.00	54.80	56.90	56.85
	57.10	57.02	54.40	57.12	55.81
Mean	**57.04**	**55.79**	**55.20**	**57.56**	**56.61**
SD	**0.42**	**1.35**	**1.06**	**0.96**	**0.71**

***** Different letters are significantly different among treatments ($p<0.05$ by DMRT)

Table B.5 Results of total Kjeldahl nitrogen content (%)

Vermicomposting period (days)	**Treatments (T)**				
	T1	**T2**	**T3**	**T4**	**T5**
15	9.43	11.46	11.42	11.53	10.47
	11.07	11.03	10.08	8.74	11.00
	10.50	11.01	9.87	9.76	9.23
Mean	**10.33**	**11.17**	**10.46**	**10.01**	**10.23**
SD	**0.83**	**0.26**	**0.84**	**1.41**	**0.91**
30	10.20	9.79	8.68	11.14	12.84
	11.61	9.62	7.72	11.77	12.72
	10.17	11.07	11.21	10.47	12.90
Mean	**10.66b**	**10.16b**	**9.20b**	**11.12ab**	**12.82a**
SD	**0.82**	**0.79**	**1.80**	**0.65**	**0.10**
45	12.50	10.98	11.05	11.47	11.61
	11.04	10.70	12.75	12.14	13.60
	10.71	10.88	12.51	13.08	13.68
Mean	**11.42**	**10.85**	**12.11**	**12.23**	**12.96**
SD	**0.95**	**0.14**	**0.92**	**0.81**	**1.17**
60	12.04	13.59	12.73	13.91	13.49
	12.79	12.36	13.68	14.71	13.21
	11.89	13.73	14.37	13.90	13.84
Mean	**12.24b**	**13.23ab**	**13.59a**	**14.17a**	**13.52a**
SD	**0.48**	**0.82**	**0.82**	**0.46**	**0.32**

* Different letters are significantly different among treatments ($p<0.05$ by DMRT)

Table B.6 Results of available phosphorus content (ppm)

Vermicomposting period (days)	Treatments (T)				
	T1	**T2**	**T3**	**T4**	**T5**
15	364.41	353.11	440.68	598.87	248.59
	406.78	522.60	502.82	384.18	403.95
	765.54	245.76	302.26	175.14	429.38
Mean	**512.24**	**373.82**	**415.25**	**386.06**	**360.64**
SD	**220.38**	**139.58**	**102.67**	**211.87**	**97.87**
30	1084.75	548.02	666.67	604.52	909.60
	694.92	847.46	451.98	423.73	915.25
	796.61	949.15	1163.84	768.36	1073.45
Mean	**858.76**	**781.54**	**760.83**	**598.87**	**966.10**
SD	**202.21**	**208.53**	**365.15**	**172.39**	**93.01**
45	1073.45	960.45	700.56	169.49	101.69
	1062.15	734.46	847.46	435.03	276.84
	677.97	621.47	790.96	242.94	355.93
Mean	**937.85a**	**772.13a**	**779.66a**	**282.49b**	**244.82b**
SD	**225.14**	**172.60**	**74.10**	**137.11**	**130.11**
60	1525.42	372.88	977.40	542.37	536.72
	1655.37	548.02	745.76	542.37	457.63
	1073.45	587.57	463.28	683.62	423.73
Mean	**1418.08a**	**502.82b**	**728.81b**	**589.45b**	**472.69b**
SD	**305.45**	**114.26**	**257.48**	**81.55**	**57.98**

***** Different letters are significantly different among treatments ($p<0.05$ by DMRT)

Table B.7 Results of exchangeable potassium content (ppm)

Vermicomposting period (days)	Treatments (T)				
	T1	**T2**	**T3**	**T4**	**T5**
15	4432.88	5234.08	5867.08	6718.88	5829.08
	4409.28	5792.98	4723.08	5941.08	4415.08
	4670.98	3224.78	4663.78	6649.88	3675.48
Mean	**4504.38**	**4750.61**	**5084.65**	**6436.61**	**4639.88**
SD	**144.76**	**1350.64**	**678.26**	**430.53**	**1094.26**
30	5319.08	7120.48	6871.28	5481.38	7557.28
	5411.68	7141.68	5565.88	7320.08	7984.28
	4714.28	5863.58	7353.48	7767.48	8255.88
Mean	**5148.35b**	**6708.58a**	**6596.88a**	**6856.31a**	**7932.48a**
SD	**378.75**	**731.87**	**924.85**	**1211.56**	**352.17**
45	5554.98	4467.38	4389.78	3315.98	3374.58
	4534.98	4074.38	3883.88	3794.28	5474.78
	3898.68	2738.68	2913.78	4593.28	3927.08
Mean	**4662.88**	**3760.15**	**3729.15**	**3901.18**	**4258.81**
SD	**835.52**	**906.18**	**750.07**	**645.33**	**1088.69**
60	7359.48	4534.88	4877.58	3659.38	5669.28
	8254.48	4128.48	3879.68	4402.38	5754.18
	8826.48	3766.88	2828.68	4206.98	5091.98
Mean	**8146.81a**	**4143.41c**	**3861.98c**	**4089.58c**	**5505.15b**
SD	**739.40**	**384.22**	**1024.56**	**385.16**	**360.32**

***** Different letters are significantly different among treatments ($p<0.05$ by DMRT)

Table B.8 Results of C/N ratio

Vermicomposting period (days)	Treatments (T)				
	T1	**T2**	**T3**	**T4**	**T5**
15	3.87	2.95	3.02	3.30	3.33
	3.04	3.29	3.39	4.38	3.26
	3.31	3.37	3.44	3.74	3.79
Mean	**3.41**	**3.20**	**3.28**	**3.81**	**3.46**
SD	**0.42**	**0.22**	**0.23**	**0.54**	**0.29**
30	3.48	2.72	4.00	1.88	2.69
	3.02	3.45	4.48	2.95	2.72
	3.43	3.13	2.99	3.13	2.71
Mean	**3.31**	**3.10**	**3.82**	**2.65**	**2.71**
SD	**0.26**	**0.37**	**0.76**	**0.68**	**0.01**
45	2.73	3.06	3.17	2.99	2.99
	3.07	3.11	2.74	2.86	2.43
	3.07	3.08	2.74	2.59	2.55
Mean	**2.96**	**3.08**	**2.88**	**2.81**	**2.66**
SD	**0.20**	**0.02**	**0.25**	**0.20**	**0.29**
60	2.73	2.33	2.58	2.45	2.46
	2.61	2.63	2.33	2.25	2.50
	2.79	2.41	2.20	2.39	2.34
Mean	**2.71**	**2.46**	**2.37**	**2.36**	**2.44**
SD	**0.09**	**0.16**	**0.19**	**0.10**	**0.08**

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