CHAPTER 4 VERMICOMPOSTING

4.1 Introduction

Since organic waste is predominant in the waste stream in Malaysia, biological treatment is recommended as a major waste management option. Waste can be converted to valuable by-products like compost and vermicast which can serve as organic fertilizer. Vermicomposting is defined as the process of digesting and breaking down of organic components using worms. The organic wastes are decomposed by earthworms into odour-free humus-like material (Suthar, 2009). There are some species of worm used in the vermicomposting of coconut husk as *Eisenia foetida, Lumbricus rubellus, Perionyx excavates, Lampito manuritii, Eudrillus euginea*, and *Pheretima elongate* (Suthar, 2008; Nari *et al*., 2006; Gajalakshmi *et al*., 2004; Tripath and Bhardwaj, 2004).

These species of worms are associated with other microorganisms at the various stages of development of a vermicomposting process (George, 2011). Earthworm castings in home gardens often contain 5 to 11 times more nitrogen, phosphorous, and potassium from the surrounding soil (Natchimuthu and Thilagavathy, 2009). Secretions in the intestinal tracts of earthworms and taking in by the earthworm through the soil make nutrients more concentrated and available for plant uptake. Red worms in vermicompost act in a similar fashion, breaking down food, agricultural wastes and other organic residues into nutrient-coconut husk compost (Natchimuthu and Thilagavathy, 2009). During vermicomposting, all characteristics of the waste such as physical, chemical and biological are changed by the action of earthworms and microorganisms (Suthar, 2009). The earthworms act as mechanical blenders throughout the vermicomposting process, and by introducing them into the organic matter, they modify its biological, physical and chemical status via gradual reduction of C-to-N ratio, and increase of the surface area exposed to microorganisms; hence creating more favorable conditions for microbial activities and further decomposition (Suthar, 2009). In this study, vermicomposting for different types of coconut waste was conducted as a potential alternative to agro-industrial waste management.

4.2 Methodology

4.2.1 Materials and Experimental Design

Three types of coconut wastes were tested in this study. These were coconut husk (CH), spent coconut flakes (SCF) and coconut shell (CS). Perforated plastic containers of 20 cm X 14 cm X 15 cm (length X width X depth) were used to carry out the experiment. Twenty worms (*Eudrilus eugeniae*) were randomly selected (fresh individual weigh $\simeq$ 20-30g) and introduced to each plastic container. The goat manure was collected from the farm inside university of Malaya. Three replicates were used for each experiment with control experiment. The layering system was used in this study as illustrated in Figure 4.1. Details of the coconut husk set-up are discussed in the following sections.

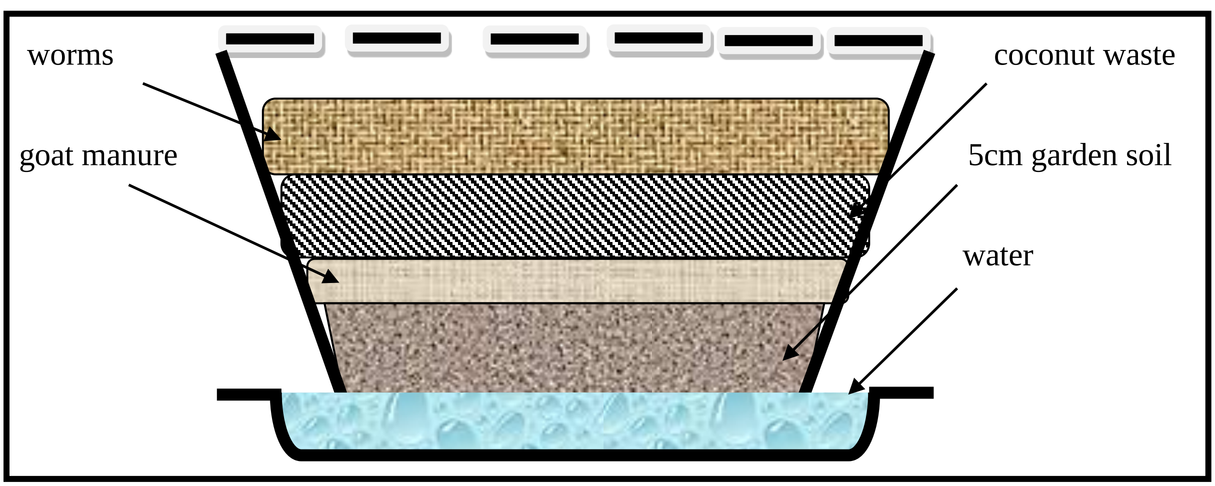

Figure 4.1: Layering system of vermicomposting experimental set-up for C2-W.

- <u>Coconut Husk (CH):</u>

Coconut husk (CH) was collected after the dehusking process. The coconut husks were chopped into a smaller size ranging from 4cm to 8cm as shown in Plate 1. Approximately 350g of waste (C1-W) was placed into the plastic containers. The experiment using coconut husk was prepared with three different ratios as shown in Table 4.1.

Table 4.1: Combination of Vermicomposting Set-ups with Coconut Husk.

Label	Combination	Ratio / %
C1	Coconut husk (CH)	100
C2	(CH) and Goat manure (GM)	70:30
C3	(CH) and Goat manure (GM)	50:50

Moisture content was maintained at 50% - 65% throughout the study (under laboratory condition). The experiments were closely monitored during the vermicomposting process.

Plate 1: Chopped Coconut Husk (CH) during the Initial Stage when *Eudrilus eugeniae* was Introduced.

Spent Coconut Flakes (SCF):

Spent coconut flakes (SCF) set-ups were prepared to give three combinations as shown in Table 4.2. Spent coconut flakes were collected and about 350 grams of waste (B1-W) were placed into the containers as shown in Plate 2.

Table 4.2: Combination of Vermicomposting Set-ups with Spent Coconut Flakes.

Label	Combination	Ratio (%)
B1	Spent coconut flakes (SCF)	100
B2	SCF + Goat manure (GM)	70:30
B3	SCF + Goat manure (GM)	50:50

Plate 2: Spent Coconut Flakes (SCF) at the Initial Stage of Vermicomposting Process.

Coconut Shell (CS):

Coconut shell (CS) experiments were prepared with three different ratios as shown in Table 4.3. Coconut shells were collected after the deshelling process. The coconut shells were chopped into a smaller size ranging from 4cm to 8cm as shown in Plate 3. Approximately 350g of waste (A1-W) was placed into the plastic containers.

Table 4.3: Combination Ratios of Coconut Shell Vermicomposting.

Label	Combination	Ratio (%)
A1	Coconut shell (CS)	100
A2	CS + Goat manure (GM)	70:30
A3	CS+ Goat manure (GM)	50:50

Plate 3: Coconut Shell (CS) at Initial Stage of Vermicomposting Process.

4.2.2 Physical and Chemical Analyses

- Physical Analysis:

Physical parameters of the vermicomposting materials (temperature and moisture content) were taken daily, while salinity and conductivity were conducted once in every five days.

Temperature:

Temperature was monitored using the handheld HANNA thermometer.

Moisture content:

The moisture content of the samples was determined by weighing fresh samples before and after oven drying at 110^{o}C for 24 hours (Mahammad, 2010).

Salinity and Conductivity

The multipurpose probe (Hach Sension 7 Benchtop Conductivity Meter) was utilized to take salinity and conductivity readings of the vermicompost materials.

- Chemical Analysis

pH determination:

The values of pH were measured once in every four days. The dissolution method was used and the solid samples were put in distilled water at 1:10 weight per volume ratio. Then pH was read using pH meter (Hach Advanced sension3).

Total Organic Carbon, Total Nitrogen and Total Phosphorus:

Total organic carbon and Total Nitrogen were analysed by CHNS elemental analysis, while Total Phosphorus was determined using Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES). Samples were taken on initial and final day (completion of vermicomposting process).

Metals and Macronutrients:

For heavy metal and macronutrient analyses, 2.0g of the samples were digested with HNO_3, HCL, H_2O_2 and HF at a 6:2:2:2ml ratio respectively in Microwave Reaction System-granite8 vessel- XF100-8 (EPA Standard), and analysed with Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES) model (Optima 5300 DV) for determining the concentration of heavy metals. Samples were taken on initial and final day (completion of vermicomposting process).

4.3 Result and Discussion

- Degradation of coconut wastes:

The degradation rates were determined via this mathematical equation.

$$\text{Degradation rate} = \frac{\text{Weight of waste (g) X 1}}{\text{Day (duration to complete) X Weight of worm (g)}}$$

The complete degradation of C3-W set-up was 42 days, while C2-W and C1-W were totally degraded after 45 and 49 days, respectively. The degradation of the various types of coconut waste is shown in Figure 4.2.

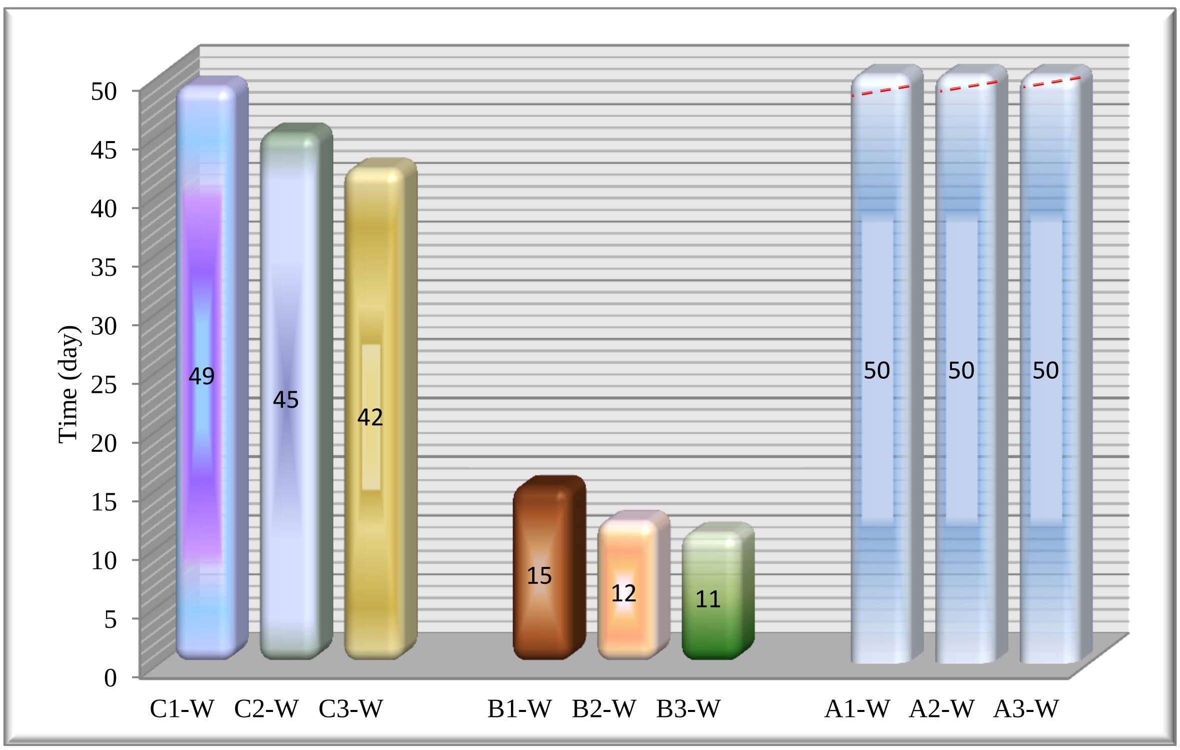

Figure 4.2: Degradation of the Vermicomposting Set-ups.

Note: C1- CH (100), C2- Goat manure (GM): CH (30:70), C3- GM: CH (50:50),
B1- SCF (100), B2- GM: SCF (30:70), B3- GM: SCF (50:50),
A1- CS (100), A2- GM: CS (30:70), A3- GM: CS (50:50), W- with worm.

The time needed for degradation of spent coconut flake set-ups, namely B3-WM, B2-WM and B1-WM, were 11, 12 and 16 days, respectively. Only partial decomposition was observed in all the coconut shell experiments even after 50 days. Spent coconut flake set-ups showed a relatively faster rate of degradation compared to coconut husk and coconut shell. Faster degradation in spent coconut flake set-ups was possibly due to the size of the spent coconut flake's particles which were smaller and softer than other two types. Additionally, spent coconut flake also contained high moisture content (52.6%) compared to coconut husk (14.3%) and coconut shell (10.5%). Spent coconut flake was also less fibrous compared to coconut husk and coconut shell. Foster (2006) had reported similar findings where spent coconut flake was found to contain low fibre (4g/100g SCF) while coconut husk and coconut shell contained high lignin at 43.0% and 36%, respectively. Therefore, it is possible that the presence of lignin and fibre might have slowed the degradation rates. This indicates that the higher the ligno-cellulose contents of the waste, the slower the vermicomposting process.

Also, degradation process was faster in the experiments (with worms) for all types of coconut wastes compared to the controls (without worms). Control experiments required a longer time for complete degradation (Figure 4.3). Faster degradation in the experiments with worms was possibly due to biological activity of microorganisms inside the worm's gut. Also, the worms' physical activities like the blending and mixing of the waste increased the surface area exposed to microorganisms; hence creating more favourable conditions for microbial activities and further decomposition.

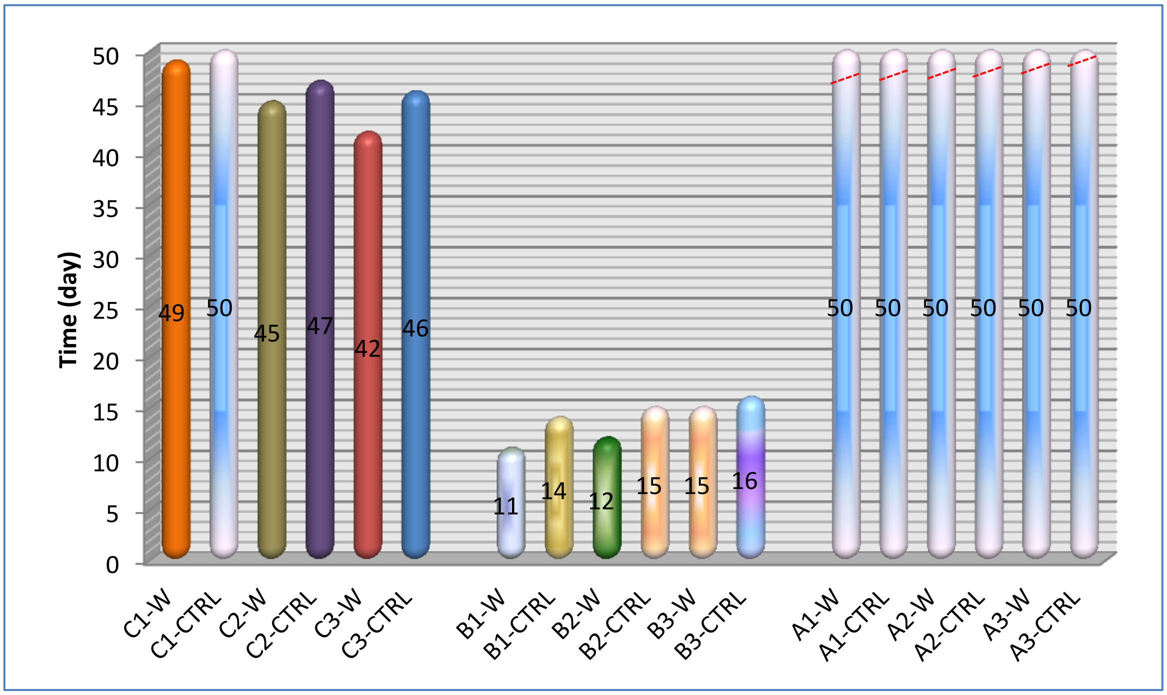

Figure 4.3: Degradation rates of the Set-ups with and without Worms.

Note: C1- CH (100), C2- Goat manure (GM): CH (30:70), C3- GM: CH (50:50),
B1- SCF (100), B2- GM: SCF (30:70), B3- GM: SCF (50:50),
A1- CS (100), A2- GM: CS (30:70), A3- GM: CS (50:50), W- with worm, CTRL- without worm.

The degradation process was relatively faster in B3 (21.4%), followed by B2 (20%), C3 (8.7%), B1 (6.3%), C2 (4.3%) and C1 (2%) as shown in Figure (4.4). The faster degradation in B3, compared to other experiments, was probably due to the presence of an adequate ratio of goat manure which added more microorganisms to the system that accelerated the degradation process. Also, the relatively faster degradation in spent coconut flake compared to coconut husk is possibly attributed to the lower content of lignin and fibre or smaller particle sizes in spent coconut flake that might have speeded the degradation rates.

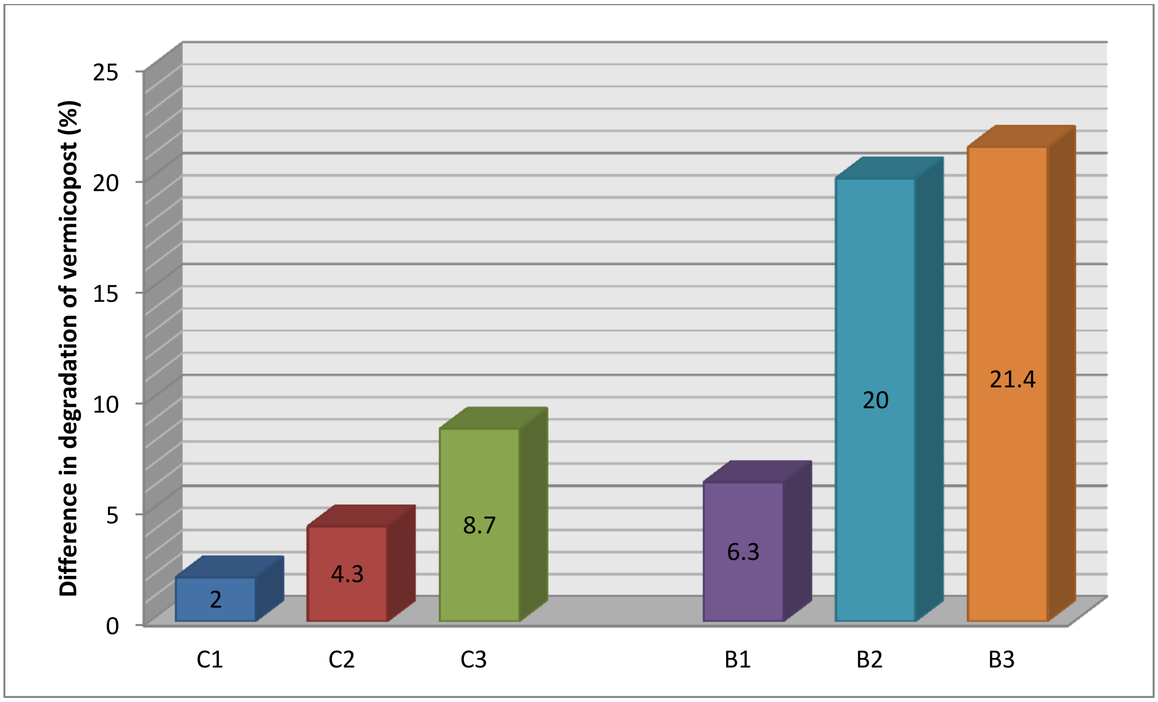

Figure 4.4: Comparative Analysis of Experimental Set-up and Control (without worm)

Note: C1- CH (100), C2- Goat manure (GM): CH (30:70), C3- GM: CH (50:50),
B1- SCF (100), B2- GM: SCF (30:70), B3- GM: SCF (50:50),
W- with worm, CTRL- without worm.

- Weight losses in the vermicomposting set-ups:

The final weight losses were found by the following mathematical equation.

$$\text{Final weight loss} = \frac{\text{First weight (g)} - \text{last weight (g)} \times 100}{\text{First weight (g)}}$$

For coconut husk, the final weight loss was highest in C3-W (33.6%), followed by C2-W (29.4%) and C1-W (21.7%) as shown in Figure 4.5. However, in SCF the weight loss was higher in B3-W (29.4%) than B2-W (28.9%) and B1-W (19.6%) (Figure 4.6). For CS, the highest weight loss was in A3-W (10.7%), followed by A2-W (8.3%) and A1-W (6.2%) as illustrated in Figure 4.7. The distinct weight losses between these experiments were possibly due to the presence of goat manure which catalysed microbial degradation of the waste. Such activities will encourage the release of CO_2 via the mineralization process of organic matter, and the release of moisture through evaporation. The moisture content of C3-W (GM: CH (50:50) was 21.3%, while B3-W (GM: SCF (50:50) was 40.5% and in A3-W (GM: CS (50:50) was 19.4%. The higher the moisture content, the faster the weight loss via evaporation process.

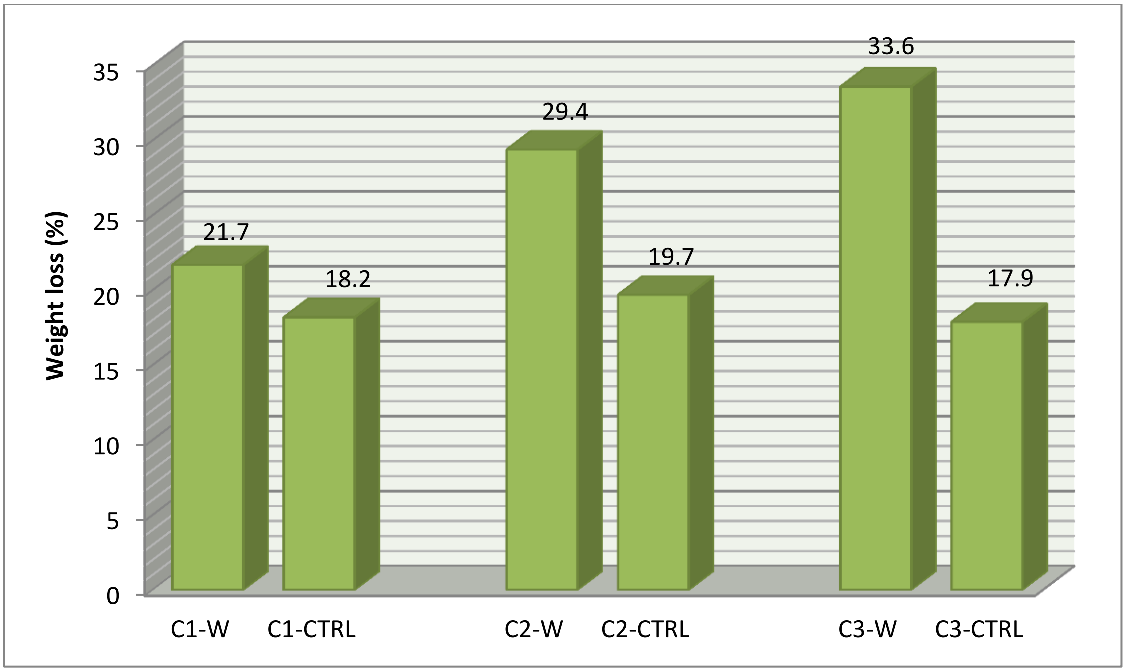

Figure 4.5: Weight Loss of the Coconut Husk (CH) at the Final Stage.

Note: C1- CH (100), C2- Goat manure (GM): CH (30:70), C3- GM: CH (50:50),
W- with worm, CTRL- without worm.

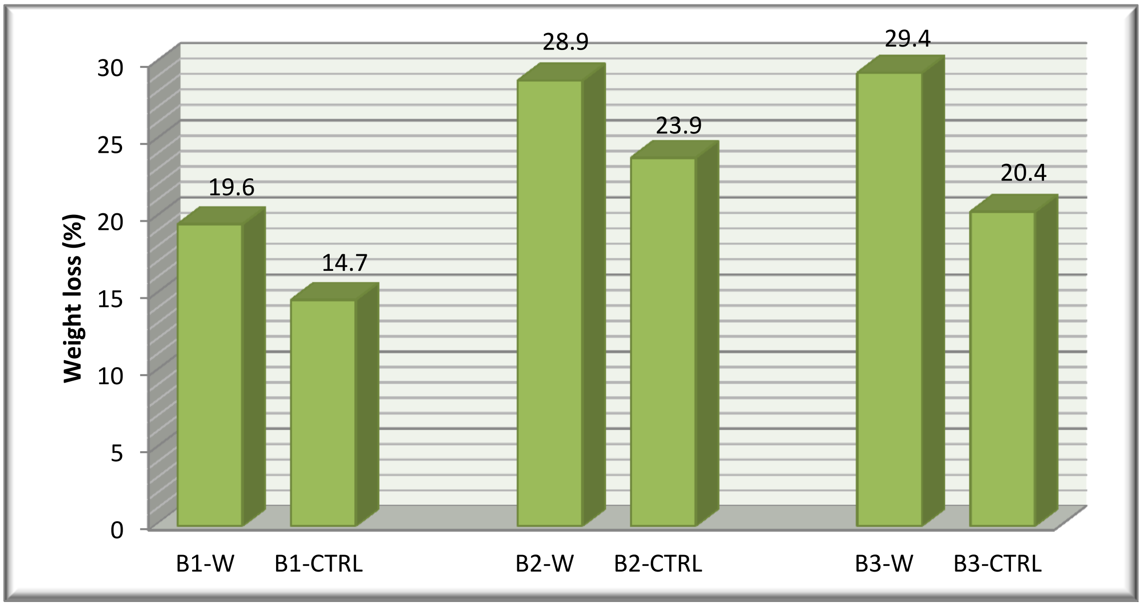

Figure 4.6: Weight Loss of the SCF at the Final Stage.

Note B1-: SCF (100), B2- GM: SCF (30:70), B3- GM: SCF (50:50), W- with worm, CTRL- without worm.

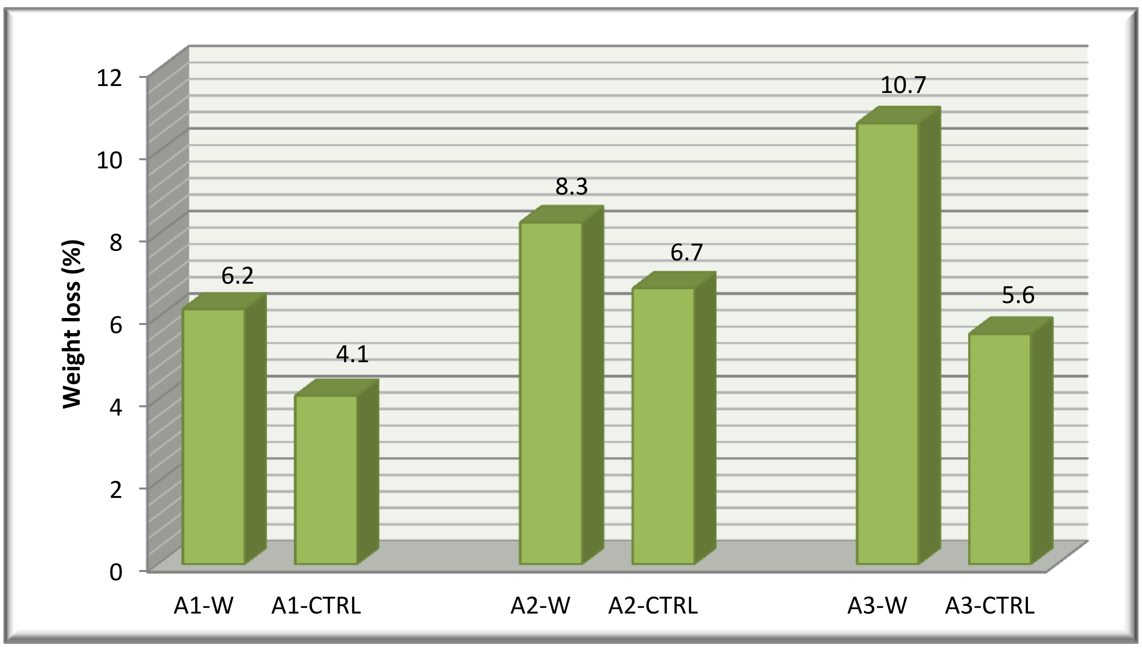

Figure 4.7: Weight Loss of CS at the Final Stage.

Note: A1- CS (100), A2- GM: CS (30:70), A3- GM: CS (50:50), W- with worm, CTRL- without worm.

The weight losses in CH experiments with worms were higher than controls (without worms). C3-W weight loss was 15.7% higher than C3-CTRL, while C2-W lost 9.7% more weight than C2-CTRL and C1-W by 3.5% when compared to C1-CTRL. Comparing with their respective control set-ups, the weight loss in SCF experiments with worms was 9% higher in B3-W, 5% higher in B2-W and 4.9% higher in B1-W as shown in Figure 4.8. Therefore, the presence of worms in the system proved to enhance the biological processes leading to higher weight loss compared to set-ups without worms. Also, the worms' physical activities like the blending, grinding and mixing of the waste increased the surface area exposed to microorganisms; hence creating more favourable conditions for microbial activities and faster decomposition. A similar scenario has been reported by Suthar (2009).

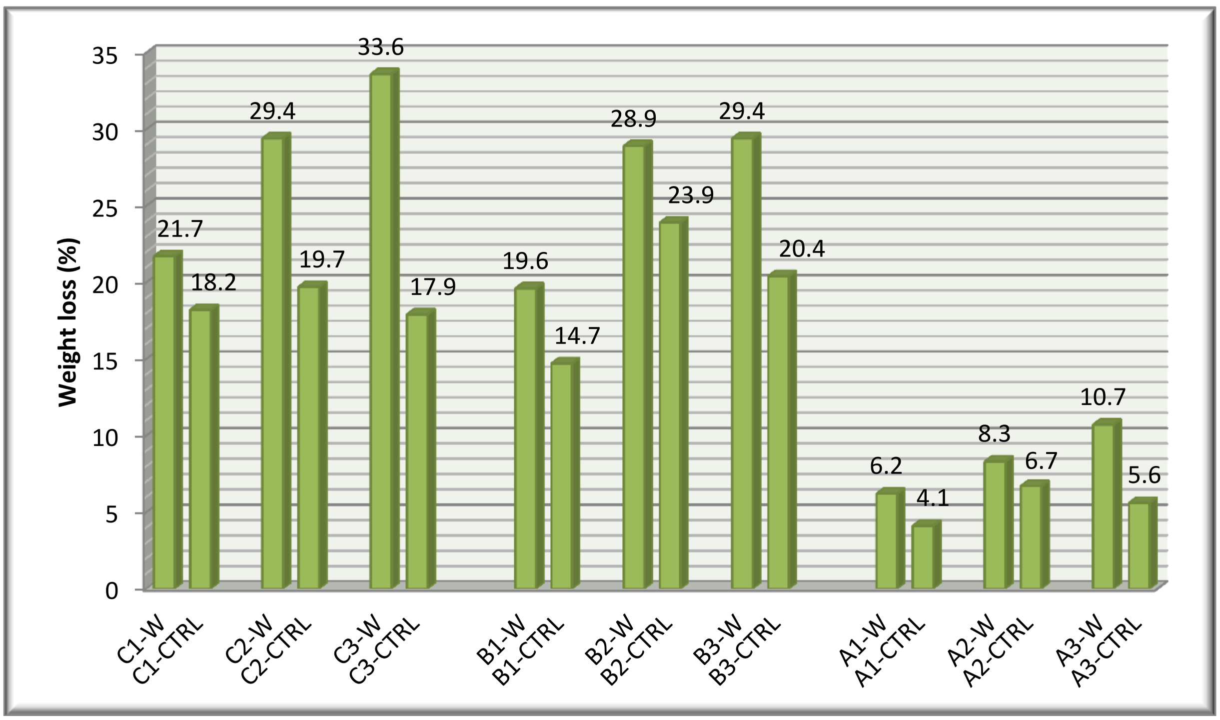

Figure 4.8: Weight Loss of Coconut Wastes at the Final Stage.

Note: C1- CH (100), C2- Goat manure (GM): CH (30:70), C3- GM: CH (50:50),
B1- SCF (100), B2- GM: SCF (30:70), B3- GM: SCF (50:50),
A1- CS (100), A2- GM: CS (30:70), A3- GM: CS (50:50), W- with worm, CTRL- without worm.

The difference in weight loss between the three coconut wastes is shown in Figure 4.9. The weight loss was higher in spent coconut flake set-ups (B3, B2 and B1) than coconut husk (C3, C2 and C1) and coconut shell (A1, A2 and A3). This was possibly due to the fact that small spent coconut flake leads to higher evaporation. Also, spent coconut flake has lower ability to retain moisture for a long period compared to coconut husk and coconut shell.

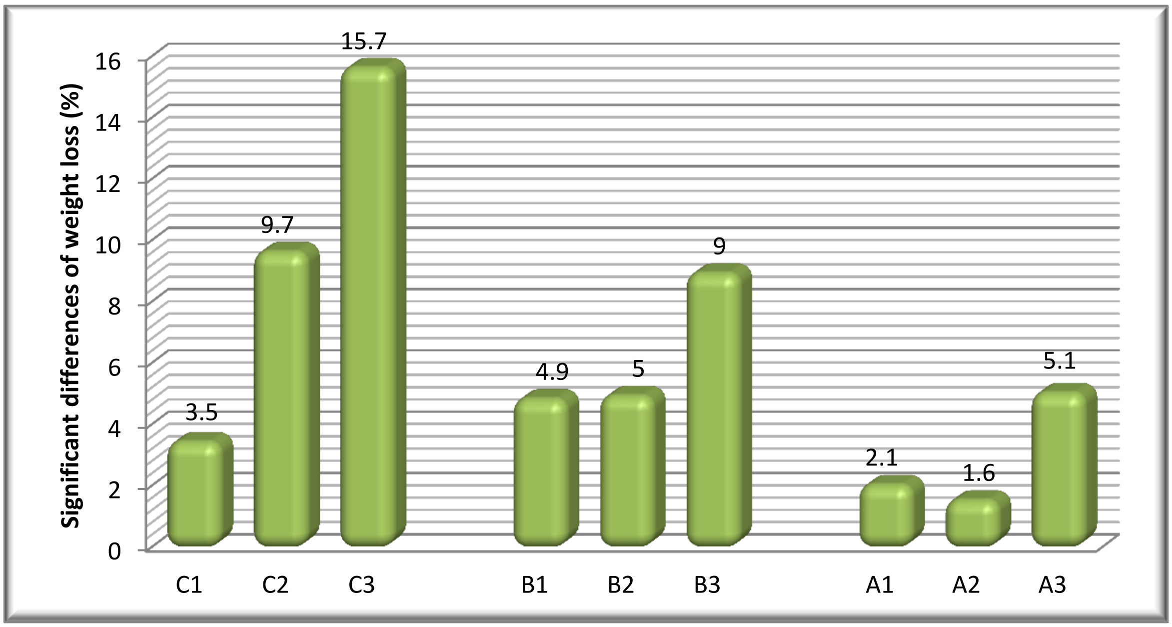

Figure 4.9: Differences Between Weight Loss in the Experiments with and without Worms.

Note: C1- CH (100), C2- Goat manure (GM): CH (30:70), C3- GM: CH (50:50),
B1- SCF (100), B2- GM: SCF (30:70), B3- GM: SCF (50:50),
A1- CS (100), A2- GM: CS (30:70), A3- GM: CS (50:50)

The difference in terms of weight loss between experiments with and without worms were clearly observed among all three types of coconut waste and have inferred that experiments with worms lost moisture faster than controls (without worms) through evaporation. The distinct weight losses between experiments with and without worms were also probably due to the worms' physical activities like the blending and mixing of the waste that increased the surface area and enhanced evaporation.

- <u>Physical Analyses:</u>

Colour change throughout the vermicomposting of coconut husk, spent coconut flake and coconut shell. The colour of the coconut husk began to change after 12 days, which was probably due to the beginning of degradation process by microorganisms, as well as earthworms' action. The colour changed completely to brown at the final stage in all of the experiments as shown in Plate 4.

Plate 4: The Colour of C2-W Totally Shifted to Brown at Final Stage.

The colour of spent coconut flake experiments changed from whitish to yellowish after 5 days. Finally, the spent coconut flake materials changed to brown after 16 days as illustrated in Plate 5.

Plate 5: The Colour of SCF Completely Changed to Brown at Final Stage.

Similarly for coconut shell, the colour changed to brownish after 50 days as shown in Plate 6.

Plate 6: The Colour of CS Changed at Final Stage.

- Electrical Conductivity (EC)

The EC values increased in coconut at the middle stage of vermicomposting. EC of C1-W increased (from 342 ± 23 µS/cm to 418 ± 36 µS/cm), while EC for C2-W increased (from 351± 72 µS/cm to 513 ± 72 µS/cm), and C3-W increased (from 377 ± 17 µS/cm to 426 ± 16 µS/cm) as shown in Figure 4.10.

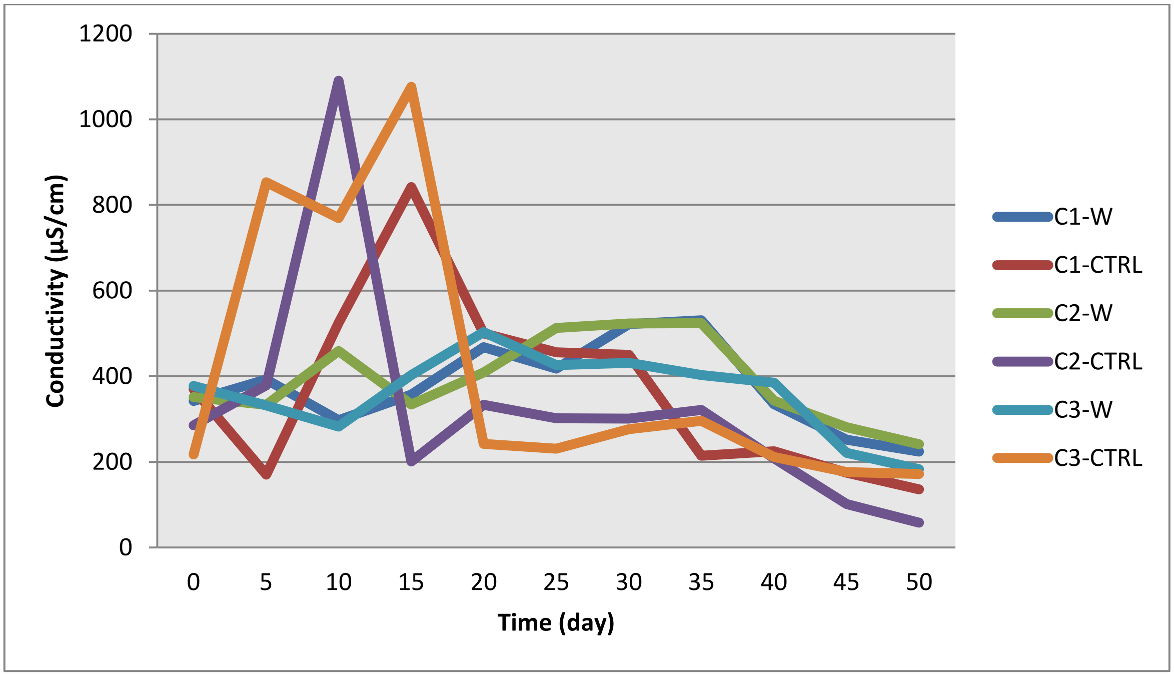

Figure 4.10: EC Value of Vermicomposting Process of Coconut Husk.

Note: C1- CH (100), C2- Goat manure (GM): CH (30:70), C3- GM: CH (50:50), W- with worm, CTRL- without worm.

For coconut shell, EC of A1-W and A2-W increased from 536 ± 31 µS/cm and 497 ± 28 µS/cm to 669 ± 30 µS/cm and 556 ± 22 µS/cm respectively (Figure 4.12). These changes of EC values were possibly due to the loss of weight of organic matter by earthworms' activities and the presence of different mineral salts in available forms (such as phosphate, ammonium, and potassium). EC values in spent coconut flake gradually decreased in all experiments (with worms) at the middle stage of vermicomposting. EC values decreased in B1-W (from 539 ± 12 µS/cm to 444 ± 62 µS/cm), while in B2-W it decreased (from 432 ± 62 µS/cm to 405 ± 14 µS/cm) and B3-W decreased (from 466 ± 31 µS/cm to 302 ± 26 µS/cm) (Figure 4.11).

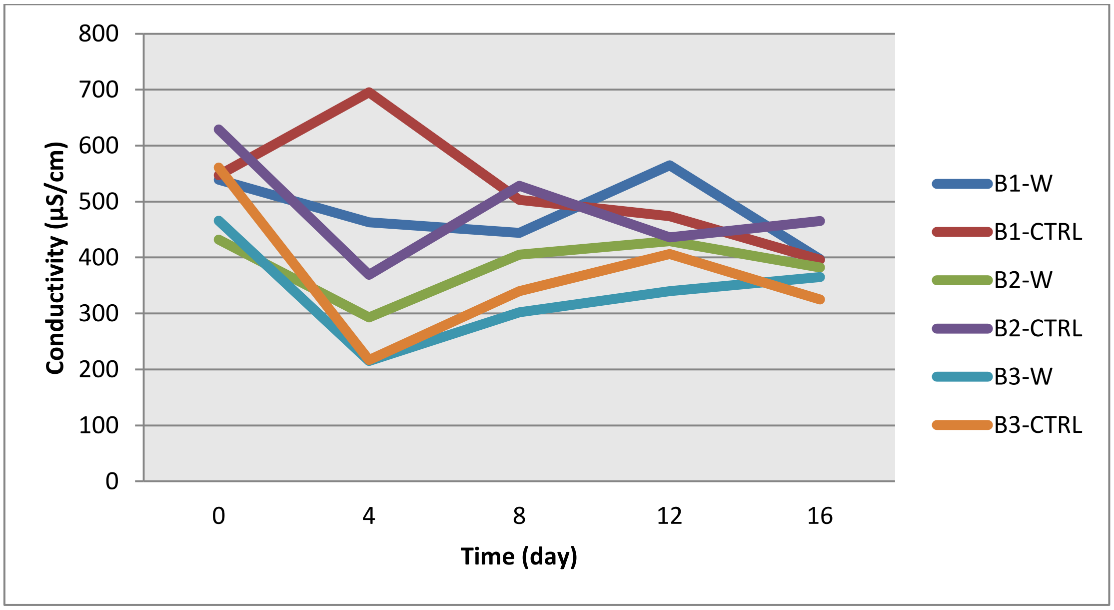

Figure 4.11: EC Value of Vermicomposting Process of SCF.

Note: SCF (100), B2- GM: SCF (30:70), B3- GM: SCF (50:50),
W- with worm, CTRL- without worm.

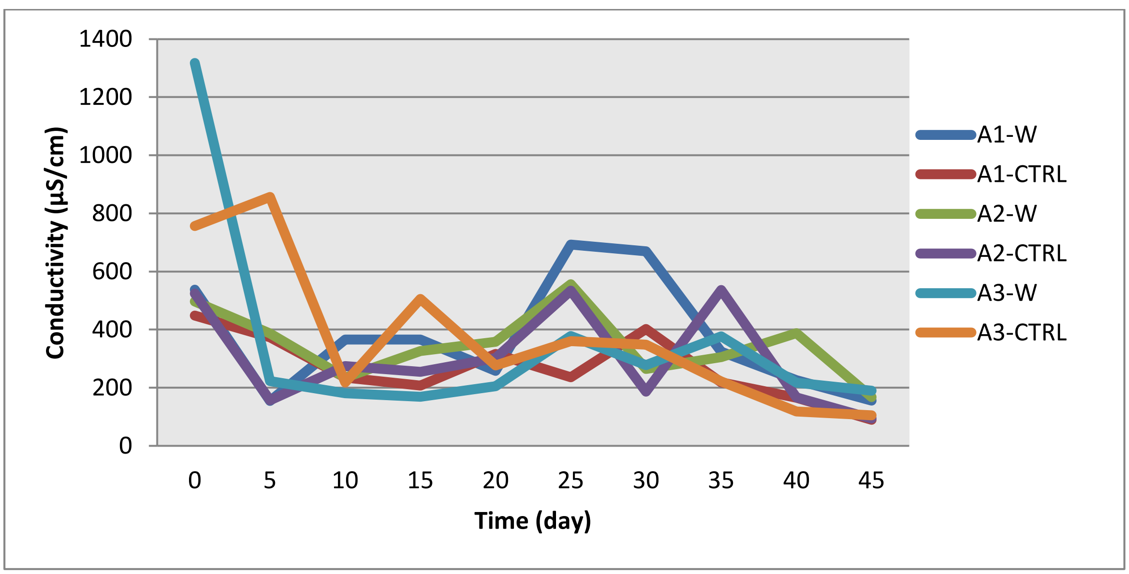

Figure 4.12: EC Value of Vermicomposting Process of CS.

Note: A1- CS (100), A2- GM: CS (30:70), A3- GM: CS (50:50), W- with worm, CTRL- without worm.

The decrease of EC value in spent coconut flake at the middle stage was possibly due to release of different mineral salts in available forms such as ammonium through the decomposition process and excretion by the worms.

Overall, EC values decreased in all of the experiments at the final stage. The highest and the lowest decreases in coconut husk were C3-W (221 ± 33 μS/cm) and C2-W (281 ± 36 μS/cm), respectively. For spent coconut flake, the highest reduction was in B1-W (397 ± 43 μS/cm) and the lowest was in B2-W (381 ± 66 μS/cm). Furthermore, EC values in all coconut shell experiments declined and the highest decrease was in A3-W (190 ± 10 μS/cm), while the lowest was in A2-W (167.6 ± 37 μS/cm). The reduction in EC values in all the experiments likely resulted from the rapid weight loss which was influenced by the release of different mineral salts as ammonium through the decomposition process and excretion by the worms. Similar scenario was reported by Asha *et al*, (2006); and Kavirag and Sharma, (2003).

In coconut husk, EC values of all the controls (without worms) at the final stage were lower compared to the experiments (with worms) as in C1-CTRL was 136 μS/cm, C2-CTRL was 58.1 μS/cm and C3-CTRL was 172 μS/cm. For spent coconut flake, the EC values in controls were lower than experiments as in B1-CTRL was 396 μS/cm, B2-CTRL was 465μS/cm and B3-CTRL was 325 μS/cm. EC values in coconut shell controls also declined as A3-CTRL was 105 μS/cm), A2-CTRL was 93.6 μS/cm) and A1-CTRL was 90.1 μS/cm. These differences between control set-ups (without worms) and test experiments (with worms) were due to the presence of earthworms that enhanced the release of different mineral salts (such as phosphate, ammonium, and potassium).

- Salinity:

Salinity values have the same trend as conductivity throughout the vermicomposting process because the soluble salts are very polar, and when salts break apart through decomposition process into ions, it gains the ability to carry electrons, raising the conductivity. The salinity values of coconut husk experiments at the initial stage ranged from lowest in C1-W (13.6 ± 5.5‰) to highest in C3-W (17.0 ± 6.1‰). Generally, salinity increases in all the experiments indicated as shown in Figure 4.13.

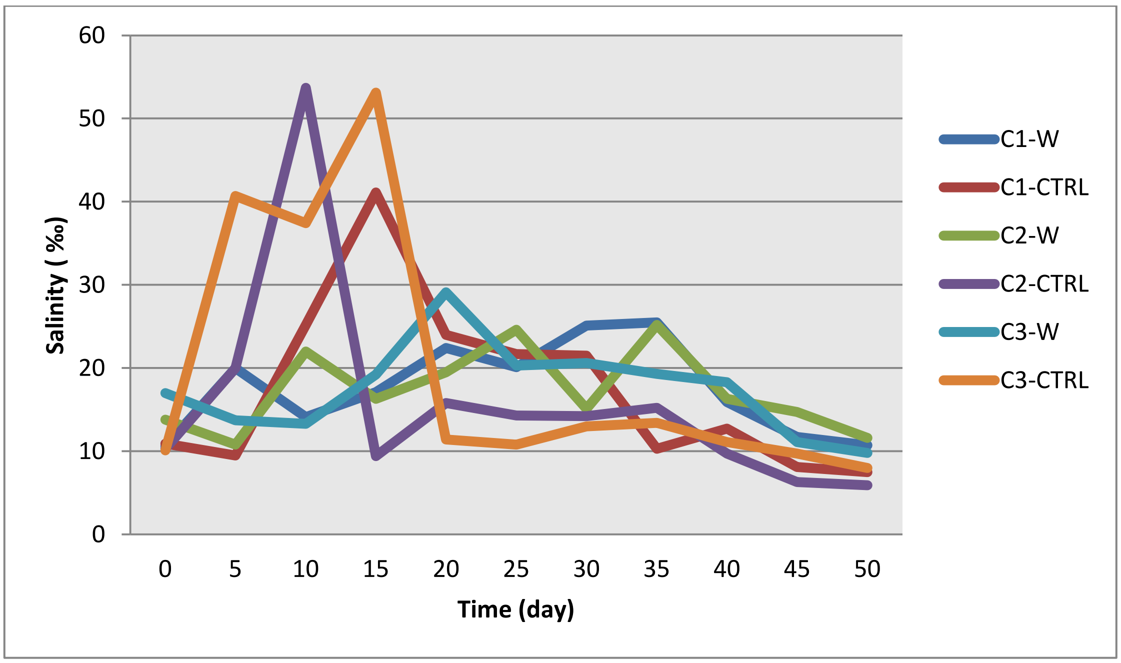

Figure 4.13: Salinity Value during Vermicomposting Process of Coconut Husk.

Note: C1- CH (100), C2- Goat manure (GM): CH (30:70), C3- GM: CH (50:50),
W- with worm, CTRL- without worm.

For spent coconut flake, Salinity values at the initial stage were highest in B1-W (25.9 ± 6.1‰) and lowest in B2-W (20.6 ± 3.1‰) as shown in Figure 4.14. Salinity values in coconut shell at initial stage ranged from highest in A3-W (60.5 ± 26‰) to lowest in A2-W (20.3± 0.1‰) as shown in Figure 4.15.

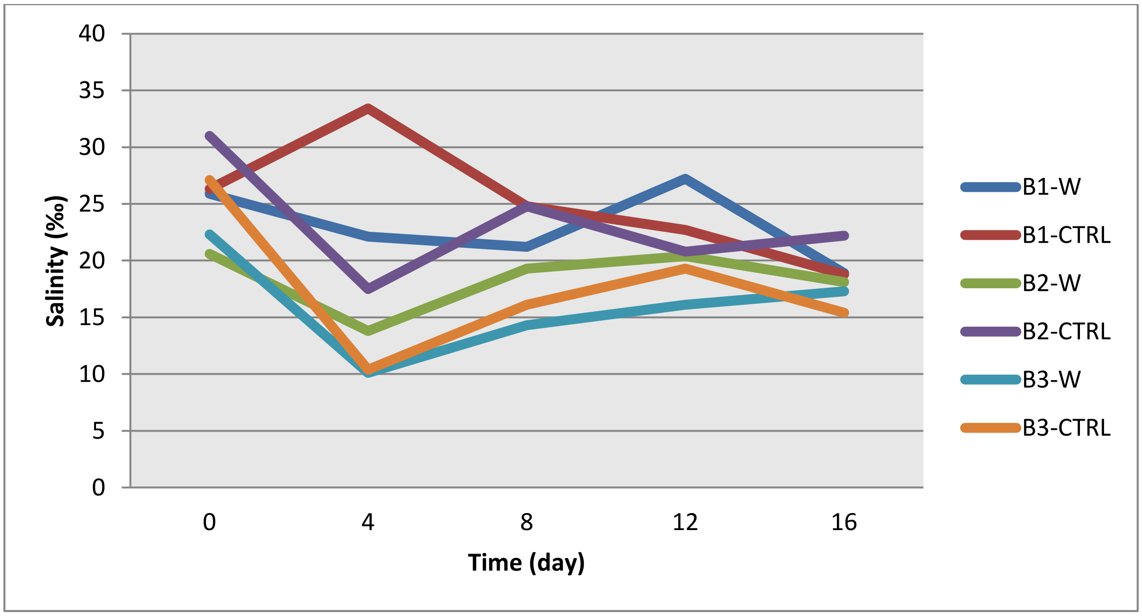

Figure 4.14: Salinity Value during Vermicomposting Process of SCF.

Note: SCF (100), B2- GM: SCF (30:70), B3- GM: SCF (50:50),
W- with worm, CTRL- without worm.

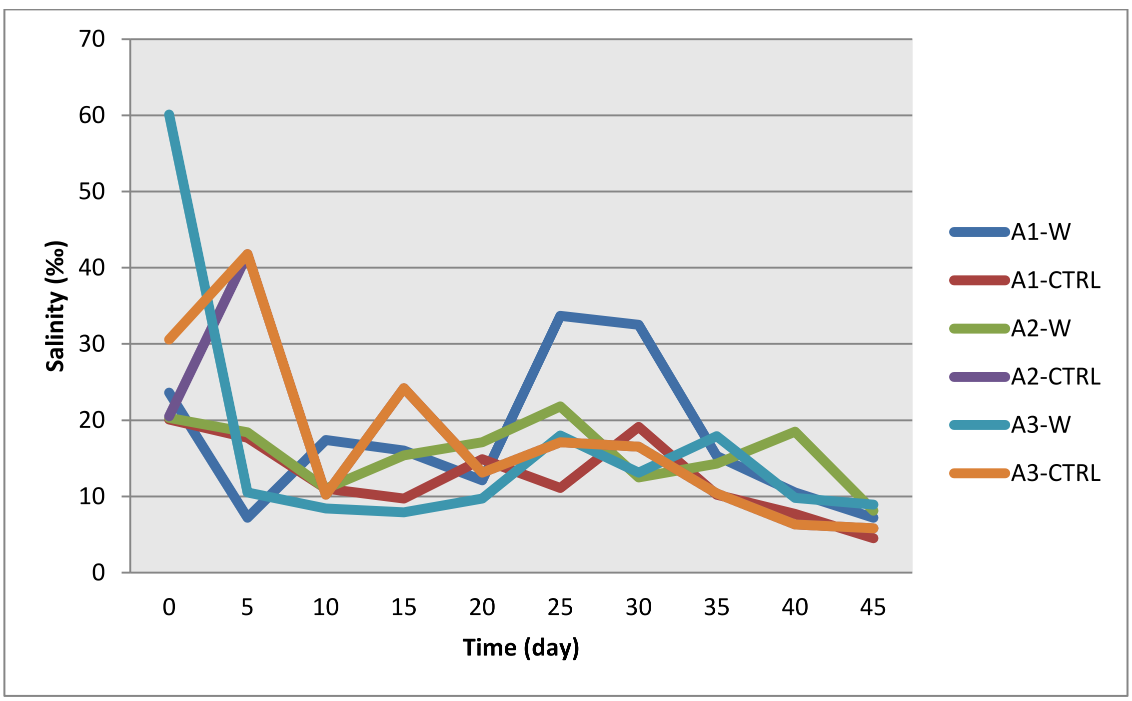

Figure 4.15: Salinity Value during Vermicomposting Process of Coconut Shell.

Note: A1- CS (100), A2- GM: CS (30:70), A3- GM: CS (50:50), W- with worm, CTRL- without worm.

The salinity values at the final stage declined in all types of coconut waste set-ups. The mass fluctuation of salinity during the vermicomposting process could be attributed to mineralisation and mobilization process through microbiological transformation of the salts. Coconut husk salinity values decreased in C1-W from 13.6 ± 5.6‰ to 10.7 ± 4.4‰, C2-W from 13.8 ± 5.5‰ to 11.6 ± 1.7‰, and C3-W from 17.0 ± 1.4‰ to 11.1 ± 2.1‰. For spent coconut flake, the salinity values also decreased in B1-W from 25.9 ± 1.4‰ to 18.8 ± 2.1‰, B2-W decreased from 20.6 ± 2.4‰ to 18.1 ± 3.2‰ and B3-W decreased from 22.3 ± 1.3‰ to 17.3 ± 2.9‰. Additionally, coconut shell salinity values also declined in A1-W from 23.6 ±2.1‰ to 7.2 ± 0.7‰, A2-W decreased from 20.3 ± 2.1‰ to 8.0 ± 1.8‰, and A3-W declined from 60.1 ± 1.2‰ to 8.9 ± 0.5‰. The reduction in salinity values at the final stage were possibly due to the decrease of EC in all the experiments and the participation of mineral salts that released from the mineralization process. The similar scenario was also addressed by Adi and Noor (2009); and Nair and Okamitsu (2010).

Salinity values of all the controls (without worms) at the final stage were lower compared to the experiments (with worms). In coconut husk, salinity values were 7.5‰ in C1-CTRL, 5.9‰ in C2-CTRL and 8.0‰ in C3-CTRL. For spent coconut flake, the salinity values also were lower in B1-CTRL (18.8‰), B2-CTRL (17.9‰) and B3-CTRL (15.4‰). Salinity values in coconut shell also decreased in A1-CTRL (4.5‰), A2-CTRL (5.8‰) and A3-CTRL (5.8‰). These distinct values between control set-ups (without worms) and test experiments (with worms) were possibly due to the earthworm activities that release different mineral salts and decreased EC as well.

- <u>Chemical Analyses:</u>
- pH value:

For coconut husk, the pH of all the experiments from first day (zero day) were slightly acidic in C1-W (pH5.2 ± 0.1), C2-W (pH5.8 ± 0.6), and C3-W (pH5.9 ± 0.1) as shown in Figure 4.16.

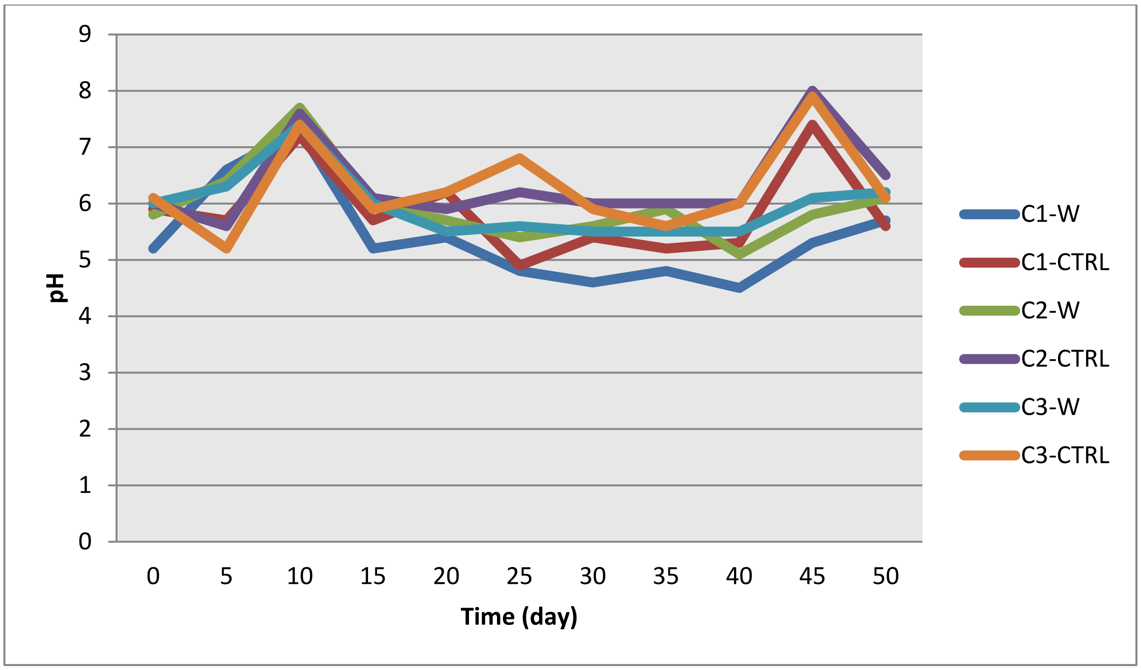

Figure 4.16: The pH Values during Vermicomposting Process of Coconut Husk.

Note: C1- CH (100), C2-GM: CH (30:70)
C3- GM: CH (50:50)
W- with worm, CTRL- without worm

The pH values in spent coconut flake were slightly alkaline from the first day (day zero). The pH in B1-WM was pH6.8 ± 1.0, pH 7.6 ± 0.1 in B2-WM and pH7.8 ± 0.1 in B3-WM (Figure 4.17). The initial pHs in coconut shell experiments were acidic as in A1 (pH 4.5 ± 0.8), A2 (pH5.5 ± 0.8) and A3 (pH 6.0 ± 0.3) (Figure 4.18).

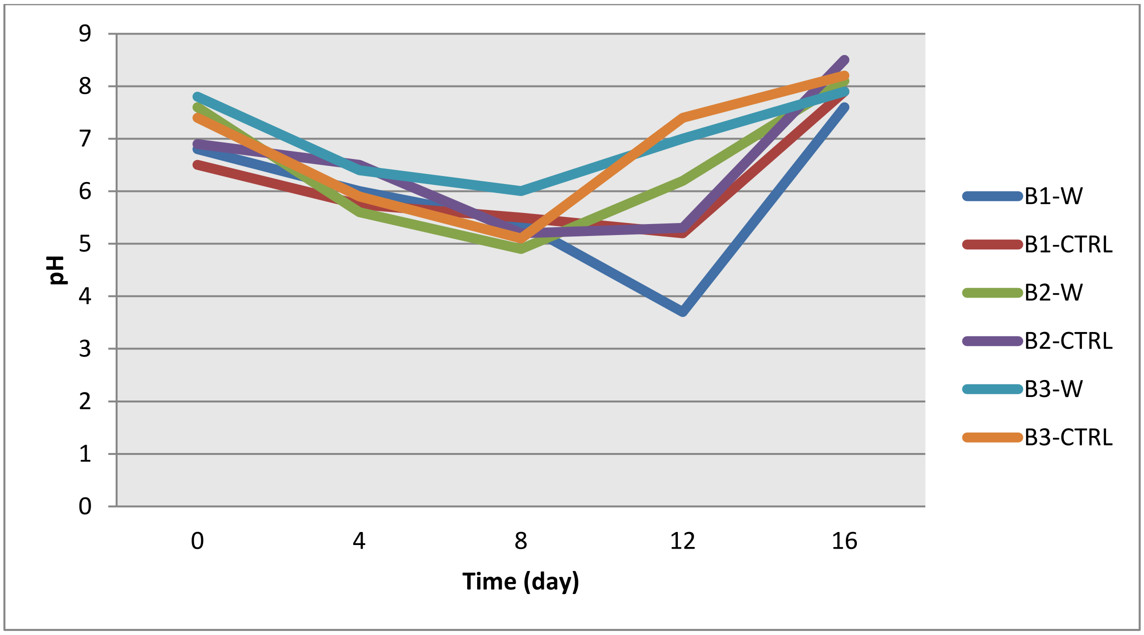

Figure 4.17: The pH Values during Vermicomposting Process of SCF.

Note: B1- SCF (100), B2-GM: SCF (30:70), B3- GM: SCF (50:50)
W- with worm
CTRL- without worm

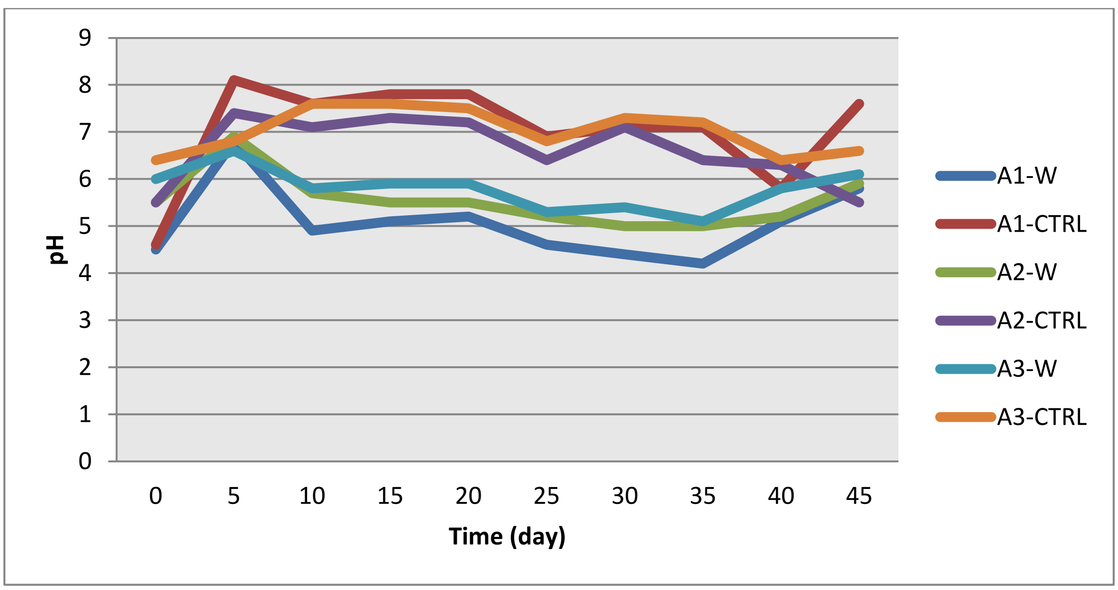

Figure 4.18: The pH Values during Vermicomposting Process of CS.

Note: A1- CS (100), A2- GM: CS (30:70), A3- GM: CS (50:50),
W- with worm, CTRL- without worm.

The pH of C1-W decreased from pH5.2 ± 0.1 to pH4.8 ± 0.2; in C2-W, pH also decreased from 5.8 ± 0.6 to 5.4 ± 0.1 and in C3-W from 5.9 ± 0.1 to 5.6 ± 0.1. For spent coconut flake, the pH in B1-W decreased from pH6.8 ± 1.0 to pH5.4 ± 0.1, in B2-W from pH7.6 ± 0.1 to pH4.9 ± 0.2 and in B3-W from pH7.8 ± 0.1 to pH6.0 ± 0.1. Additionally, pH values in coconut shell also declined in A1-W from pH5 ± 0.8 to pH4.6 ± 0.4, in A2-W from pH5.5 ± 0.8 to pH5.2 ± 0.2 and in A3-W from pH6.0 ± 0.3 to pH5.3 ± 0.1. These changes in pH values were possibly due to the change of waste to CO_2, NO_3^- (retention of nitrogen) and organic acid through decomposition process by microorganisms. Similar scenario also reported by Suthar and Singh (2008).

The pH values at the final stage increased in all types of coconut waste set-ups. For coconut husk, pH values increased in C1-W from pH4.8 ± 0.2 to pH5.7 ± 0.4, in C2-W from pH5.8 ± 0.6 to pH6.1 ± 0.6 and in C3-W from pH5.9 ± 0.1 to pH5.9 ±0.4. The pH of spent coconut flake increased in B1-W from pH5.4 ± 0.1to pH7.6 ± 0.4, in B2-W from pH4.9 ± 0.2 to pH8.1 ± 0.1 and in B3-W increased from pH6.0 ± 0.1 to pH7.9 ± 0.3. Furthermore, pH values in coconut shell also increased in A1-W from pH4.6 ± 0.4 to pH5.8 ± 0.5, in A2-W from pH5.2 ± 0.2 to pH5.8 ± 0.7 and in A3-W from pH5.3 ± 0.1 to pH6.1 ± 0.8. These increases in pH values at final stage of vermicomposting were possibly attributed to decomposition of nitrogenous substrates resulting in the production of ammonia which formed a large proportion of the nitrogenous matter which was excreted by earthworms. Similar scenario was also addressed by Muthukumaravel *et al* (2008). In addition, the pH values at the final stage also increased in the control set-ups (without worms). The pH values of coconut husk controls increased in C1-CTRL from pH5.5 to pH5.6, in C2-CTRL from pH6.0 to pH6.5 and in C3- CTRL from pH6.0 to pH6.1. For spent coconut flake, the pH values increased in B1-CTRL from pH6.5 to pH7.9, in B2-CTRL from pH6.9 to pH8.5 and in B3-CTRL from pH7.4 to pH8.2. The pH values in coconut shell controls also increased as in A1-CTRL from pH4.6 to pH7.6, in A2-CTRL from pH5.4 to pH5.5 and in A3-CTRL from pH6.4 to pH6.6. The pH increase at the final stage of vermicomposting in all the controls of all types of coconut waste were possibly due to protein degradation to ammonia by microorganisms. Similar scenario also addressed by Ndegwa and Thompson (2000).

- Metals and Macronutrient Analyses:

The coconut husk samples were analysed for heavy metals and macronutrients such as Ca, Mg, Na, Pb, Mn, Zn, Cu, Cd, Fe and Ni as shown in Table 4.4. For coconut husk, the concentrations of Ca, Na, Pb, Cu and Ni at final stage of vermicomposting declined in all of the experiments (with and without worms), but the concentration of Mg, Mn, Zn and Fe were slightly increased. The concentration of Pb, Cu and Ni decreased at the final stage in spent coconut flake, while the concentration of Ca, Mg, Na, Mn, Zn and Fe increased (Table 4.5).

Table 4.4: Metals and Macronutrient Concentrations in Coconut Husk.

sample	Zn(mg/kg)			Cd(mg/kg)			Cu(mg/kg)			Fe(mg/kg)			Ni(mg/kg)		
	Initial stage	Middle stage	Final stage	Initial stage	Middle stage	Final stage	Initial stage	Middle stage	Final stage	Initial stage	Middle stage	Final stage	Initial stage	Middle stage	Final stage
C1-W	0.03	0.02	0.02	Nd	Nd	Nd	0.002	0.002	0.002	1.15	1.17	1.35	0.0005	0.0006	0.0004
C2-W	0.02	0.02	0.02	Nd	Nd	Nd	0.002	0.002	0.001	0.99	1.08	1.07	0.0001	0.0002	0.0005
C3-W	0.02	0.02	0.02	Nd	Nd	Nd	0.002	0.002	0.002	1.08	1.06	1.33	0.0003	0.0002	0.0003
C1-CTRL	0.02	0.01	0.02	Nd	Nd	Nd	0.002	0.002	0.001	1.12	1.17	1.15	0.0003	0.0004	0.0002
C2-CTRL	0.03	0.02	0.02	Nd	Nd	Nd	0.003	0.002	0.001	1.23	0.90	1.11	0.0005	0.0004	0.0003
C3-CTRL	0.02	0.02	0.02	Nd	Nd	Nd	0.003	0.002	0.002	0.94	1.03	1.11	0.0006	0.0002	0.0004
EU limit (mg/kg)	210-4,000			0.7 - 10			70 - 600			-			20 - 200		
US biosolid (mg/kg)	2,800			39			1,500			-			420		

sample	Ca(mg/kg)			Mg(mg/kg)			Na(mg/kg)			Pb(mg/kg)			Mn(mg/kg)		
	Initial stage	Middle stage	Final stage	Initial stage	Middle stage	Final stage	Initial stage	Middle stage	Final stage	Initial stage	Middle stage	Final stage	Initial stage	Middle stage	Final stage
C1-W	0.31	0.18	0.29	0.22	0.14	0.15	0.08	0.07	0.09	0.082	0.004	0.004	0.01	0.01	0.01
C2-W	0.26	0.24	0.23	0.17	0.18	0.11	0.08	0.08	0.07	0.003	0.004	0.002	0.01	0.01	0.01
C3-W	0.68	0.22	0.31	0.34	0.15	0.12	0.11	0.07	0.09	0.005	0.004	0.004	0.02	0.01	0.01
C1-CTRL	0.37	0.17	0.22	0.25	0.14	0.16	0.10	0.07	0.08	0.005	0.004	0.004	0.01	0.01	0.01
C2-CTRL	0.39	0.22	0.23	0.21	0.16	0.13	0.09	0.08	0.07	0.004	0.005	0.004	0.02	0.01	0.01
C3-CTRL	0.69	0.21	0.24	0.35	0.16	0.15	0.10	0.78	0.08	0.004	0.003	0.003	0.02	0.01	0.01
EU limit (mg/kg)	-			-			-			70 - 1,000			-		
US biosolid (mg/kg)	-			-			-			300			-		

Note: C1- CH (100), C2-GM: CH (30:70), C3- GM: CH (50:50), W- with worm, CTRL- without worm.

Table 4.5: Metals and Macronutrient Concentrations in SCF.

sample	Ca(mg/kg)			Mg(mg/kg)			Na(mg/kg)			Pb(mg/kg)			Mn(mg/kg)		
	Initial stage	Middle stage	Final stage	Initial stage	Middle stage	Final stage	Initial stage	Middle stage	Final stage	Initial stage	Middle stage	Final stage	Initial stage	Middle stage	Final stage
B1-W	1.43	2.39	1.61	0.29	0.34	0.30	0.11	0.11	0.12	0.004	0.002	0.003	0.013	0.018	0.015
B2-W	1.31	2.54	2.18	0.26	0.39	0.36	0.12	0.13	0.15	0.003	0.002	0.004	0.013	0.012	0.019
B3-W	1.27	1.84	1.54	0.27	0.32	0.32	0.13	0.13	0.13	0.004	0.003	0.003	0.015	0.019	0.017
B1-CTRL	1.06	1.85	1.06	0.21	0.34	0.27	0.09	0.13	0.12	0.003	0.002	0.003	0.009	0.016	0.012
B2-CTRL	0.92	1.55	1.26	0.30	0.27	0.29	0.12	0.15	0.14	0.004	0.003	0.003	0.012	0.018	0.013
B3-CTRL	1.44	3.02	1.53	0.29	0.39	0.35	0.14	0.14	0.14	0.003	0.003	0.004	0.013	0.020	0.017
EU limit (mg/kg)	-			-			-			70 - 1,000			-		
US biosolid (mg/kg)	-			-			-						-		

sample	Zn(mg/kg)			Cd(mg/kg)			Cu(mg/kg)			Fe(mg/kg)			Ni(mg/kg)		
	Initial stage	Middle stage	Final stage	Initial stage	Middle stage	Final stage	Initial stage	Middle stage	Final stage	Initial stage	Middle stage	Final stage	Initial stage	Middle stage	Final stage
B1-W	0.010	0.013	0.011	Nd	Nd	Nd	0.002	0.002	0.002	0.89	1.09	1.11	0.0009	0.0005	0.0003
B2-W	0.008	0.013	0.012	Nd	Nd	Nd	0.001	0.001	0.002	0.74	1.15	1.13	0.0004	0.0005	0.0001
B3-W	0.009	0.015	0.013	Nd	Nd	Nd	0.002	0.002	0.001	1.20	1.32	1.36	0.0001	0.0005	0.0003
B1-CTRL	0.006	0.011	0.008	Nd	Nd	Nd	0.001	0.001	0.001	0.58	1.07	0.81	0.0006	0.0004	0.0003
B2-CTRL	0.007	0.014	0.009	Nd	Nd	Nd	0.002	0.002	0.002	0.66	1.12	0.88	0.0006	0.0002	0.0003
B3-CTRL	0.007	0.012	0.011	Nd	Nd	Nd	0.001	0.002	0.002	0.77	1.19	1.78	0.0004	0.0005	0.0004
EU limit (mg/kg)	210-4,000			0.7 - 10			70 - 600			-			20 - 200		
US biosolid (mg/kg)	2,800			39			1,500			-			420		

Note: B1- SCF (100), B2-GM: SCF (30:70), B3- GM: SCF (50:50), W- with worm, CTRL- without worm.

Additionally, the concentration of Ca, Mg, Na, Cu and Ni decreased at final stage of vermicomposting in coconut shell. However, the concentration of Pb, Mn, Zn and Fe increased as shown in Table 4.6.

Table 4.6: Metals and Macronutrient Concentrations in Coconut Shell.

sample	Ca(mg/kg)			Mg(mg/kg)			Na(mg/kg)			Pb(mg/kg)			Mn(mg/kg)		
	Initial stage	Middle stage	Final stage	Initial stage	Middle stage	Final stage	Initial stage	Middle stage	Final stage	Initial stage	Middle stage	Final stage	Initial stage	Middle stage	Final stage
A1-W	0.59	0.20	0.21	0.27	0.11	0.16	0.26	0.09	0.11	0.003	0.004	0.003	0.012	0.585	0.190
A2-W	5.28	0.24	0.38	0.21	0.12	0.18	0.21	0.09	0.10	0.003	0.004	0.004	0.011	0.528	0.243
A3-W	1.52	0.23	0.30	0.55	0.13	0.18	0.25	0.08	0.09	0.003	0.004	0.003	0.024	1.524	0.226
A1-CTRL	0.23	1.16	1.17	0.09	0.33	0.35	0.12	0.21	0.20	0.002	0.004	0.004	0.005	0.232	1.160
A2-CTRL	1.26	1.00	0.97	0.57	0.25	0.26	8.22	8.990	8.91	0.004	0.004	0.004	0.020	0.122	1.004
A3-CTRL	0.75	1.24	1.04	0.28	0.37	0.34	0.28	0.20	0.19	0.003	0.004	0.004	0.012	0.755	1.241
EU limit (mg/kg)	-			-			-			70 - 1,000			-		
US biosolid (mg/kg)	-			-			-						-		

sample	Zn(mg/kg)			Cd(mg/kg)			Cu(mg/kg)			Fe(mg/kg)			Ni(mg/kg)		
	Initial stage	Middle stage	Final stage	Initial stage	Middle stage	Final stage	Initial stage	Middle stage	Final stage	Initial stage	Middle stage	Final stage	Initial stage	Middle stage	Final stage
A1-W	0.009	0.014	0.013	Nd	Nd	Nd	0.009	0.017	0.002	0.78	0.81	1.12	0.0014	0.0006	0.0002
A2-W	0.013	0.017	0.016	Nd	Nd	Nd	0.013	0.002	0.002	0.90	0.97	1.11	0.0007	0.0008	0.0002
A3-W	0.015	0.015	0.015	Nd	Nd	Nd	0.017	0.002	0.002	0.57	0.95	1.05	0.0008	0.0001	0.0003
A1-CTRL	0.006	0.015	0.019	Nd	Nd	Nd	0.006	0.002	0.002	0.44	1.30	1.60	0.0004	0.0002	Nd
A2-CTRL	0.018	0.015	0.016	Nd	Nd	Nd	0.003	0.002	0.001	0.81	1.42	1.47	0.0005	0.0004	0.0003
A3-CTRL	0.009	0.017	0.017	Nd	Nd	Nd	0.002	0.002	0.002	0.57	1.40	1.34	0.0009	0.0004	0.0005
EU limit (mg/kg)	210-4,000			0.7 - 10			70 - 600			-			20 - 200		
US biosolid (mg/kg)	2,800			39			1,500			-			420		

Note: A1- CS (100), A2-GM: CS (30:70), A3- GM: CS (50:50), W- with worm, CTRL-without worm.

The concentrations for all of the elements in all types of coconut waste were below the detection limit and were within the acceptable range of both US Biosoild limit and EU limit. The concentration of some heavy metals and macronutrients declined at the final stage of vermicomposting in all types of coconut waste. The reductions in concentration of these elements were possibly due to mineralization and degradation process of the feed materials or leaching of the metals during watering the experiments. Similar scenario was also addressed by Suthar (2009). On the other hand, the concentration of some other macronutrients increased at the final stage in all types of coconut waste. These increases in the concentration of the elements were possibly due to the mineralization process and massive decomposition process of the raw materials. Similar scenario was reported by Fauziah and Agamuthu (2009). Cd was not detected in any of the experiments.

- <u>Phosphorus (P):</u>

The phosphorus values decreased in coconut husk at the middle stage of vermicomposting. The phosphorus value of C1-W decreased from 8.65mg/l to 4.62mg/l, in C2-W from 7.52mg/l to 6.84mg/l and in C3-W from 18.42mg/l to 7.03mg/l (Figure 4.19). For spent coconut flake, the phosphorus value of B1-W increased at the middle stage from 10.87mg/l to 13.18mg/l, in B2-W from 10.02mg/l to 15.68mg/l and B3-W from 9.92mg/l to 13.44mg/l as shown in Figure (4.20).

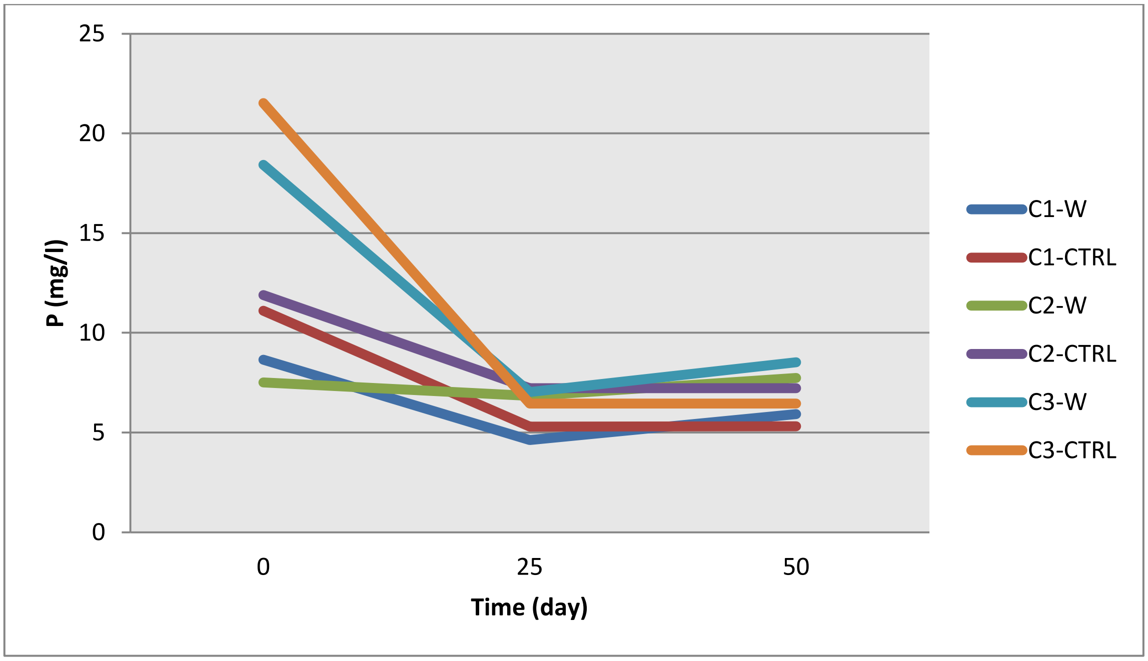

Figure 4.19: Value of Phosphorus during of Vermicomposting of Coconut Husk.

Note: C1- CH (100), C2-GM: CH (30:70), C3- GM: CH (50:50)
W- with worm, CTRL- without worm.

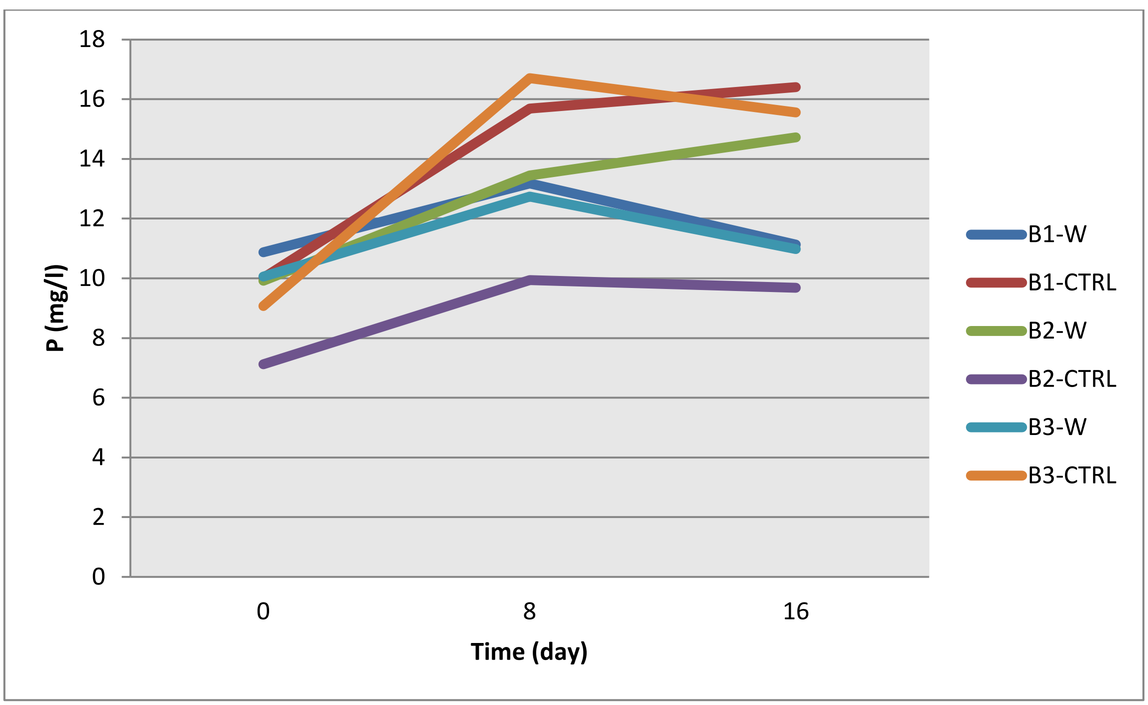

Figure 4.20: Value of Phosphorus during of Vermicomposting of SCF.

Note: B1- SCF (100), B2-GM: SCF (30:70), B3- GM: SCF (50:50)
W- with worm, CTRL- without worm

Moreover, the phosphorus values in coconut shell also decreased at the middle stage of vermicomposting. The phosphorus of A1-W decreased from 15.54mg/l to 4.85mg/l, in A2-W from 11.25mg/l to 6.16mg/l and in A3-W from 56.23mg/l to 6.91mg/l (Figure 4.18).

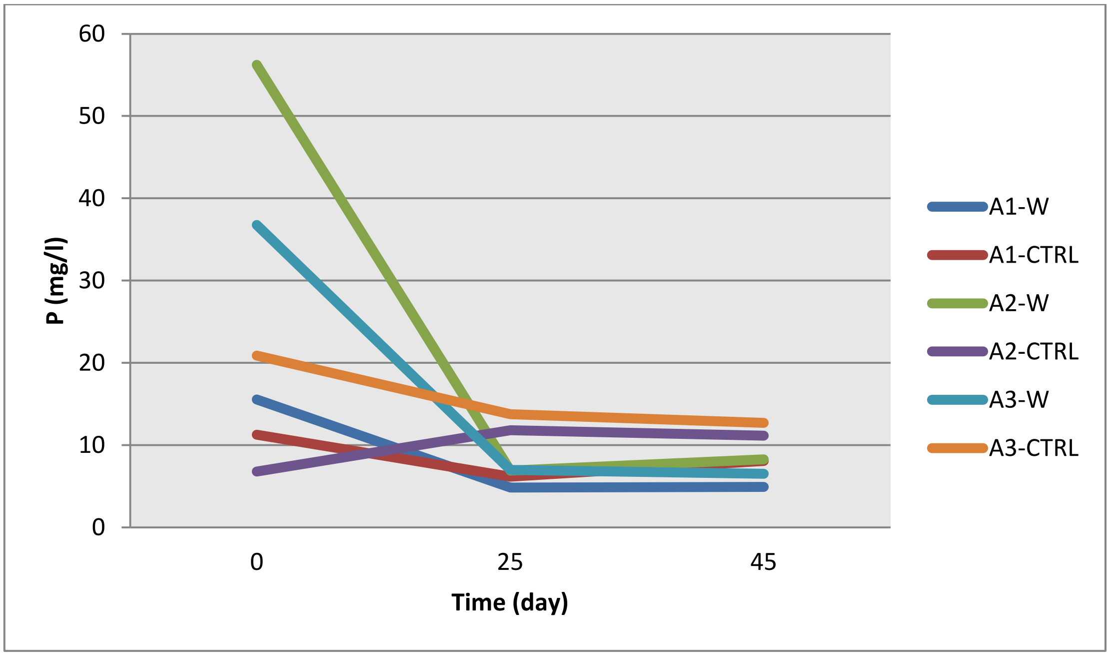

Figure 4.21: Value of Phosphorus during of Vermicomposting of CS.

Note: A1- CS (100), A2-GM: CS (30:70), A3- GM: CS (50:50)
W- with worm, CTRL- without worm

The reduction of phosphorus value in coconut husk and coconut shell at middle stage of vermicomposting could be attributed to the mineralization of phosphorus from bacterial and faecal phosphate activity of earthworms or micro-biota in the gut of earthworms. Similar scenario was addressed by Asha *et al* (2006). However, the increase of phosphorus value in spent coconut flake was also possibly due to the presence of high ratio of phosphorus in the vermibed or the physical breakdown of the materials by worms. Further release of P might also be attributed to the P-solubilizing microorganisms present in worm casts. Similar scenario was reported by Edwards and Bohlen (1972); and Suthar (2007). The highest reduction at final stage of phosphorus value in coconut husk was in C3-W from 18.42mg/l to 8.53mg/l, while the highest reduction of phosphorus value in coconut shell was in A3-W from 56.23mg/l to 8.25mg/l. For spent coconut flake, the phosphorus value increased at the final stage and the highest increase was in B2-W (10.02mg/l to 16.40mg/l). The phosphorus values of all the controls (without worms) at the final stage of vermicomposting of coconut husk and coconut shell decreased. The highest reduction of phosphorus value in coconut husk controls was in C3-CTRL from 21.52mg/l to 6.45mg/l, while the highest reduction in coconut shell controls was in A2-CTRL from 36.77mg/l to 6.50mg/l. But, the phosphorus value of spent coconut flake increased in all the controls and the highest increase was in B3-CTRL from 9.07mg/l to 15.56mg/l. The highest reduction in C3-CTRL and A2-CTRL was possibly due to the presence of GM which enhance the mineralization and mobilization of phosphorus.

- Total Potassium (TK):

The TK values decreased in coconut husk at final stage of vermicomposting. The TK value of C1-W decreased from 43.58mg/l to 38.85mg/l. In C2-W, it decreased from 33.51mg/l to 30.27mg/l and in C3-W it went from 47.24mg/l to 34.66mg/l (Figure 4.19). For spent coconut flake, the TK value of B1-W increased at the final stage of vermicomposting from 39.74mg/l to 57.08mg/l, in B2-W from 30.55mg/l to 51.70mg/l and in B3-W from 36.03mg/l to 49.52mg/l as shown in Figure (4.20).

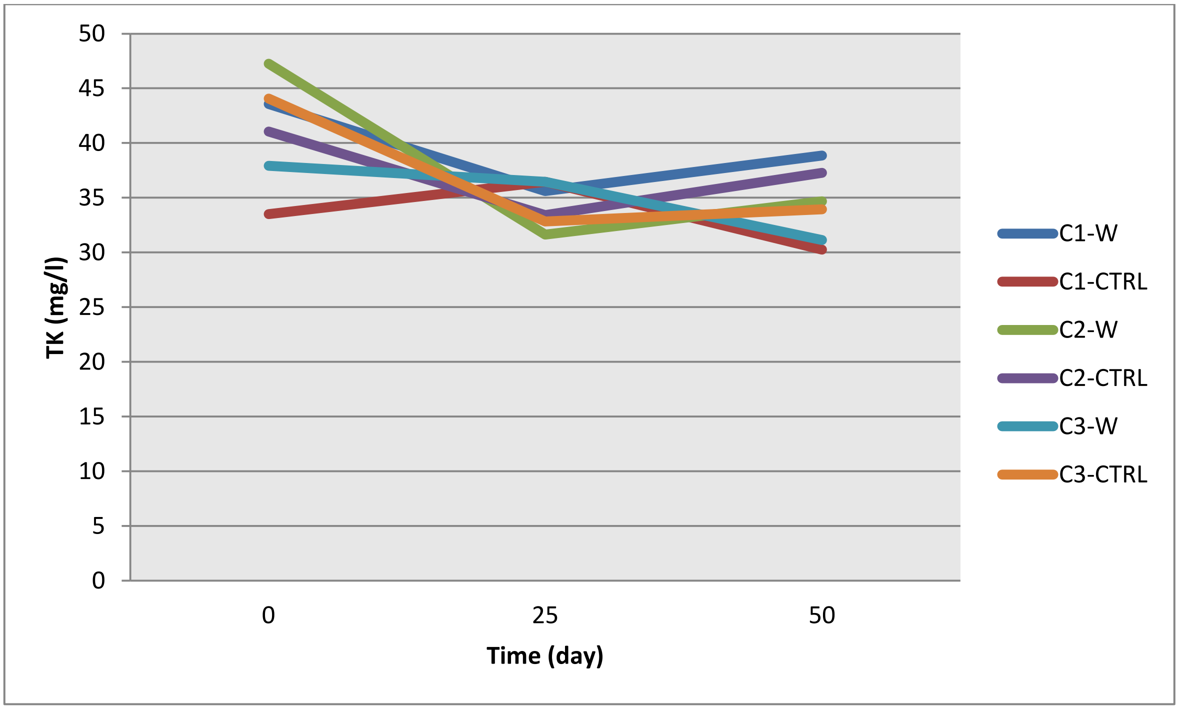

Figure 4.22: The Value of Total Potassium during Vermicomposting of Coconut Husk.

Note: C1- CH (100), C2-GM: CH (30:70), C3- GM: CH (50:50)
W- with worm, CTRL- without worm

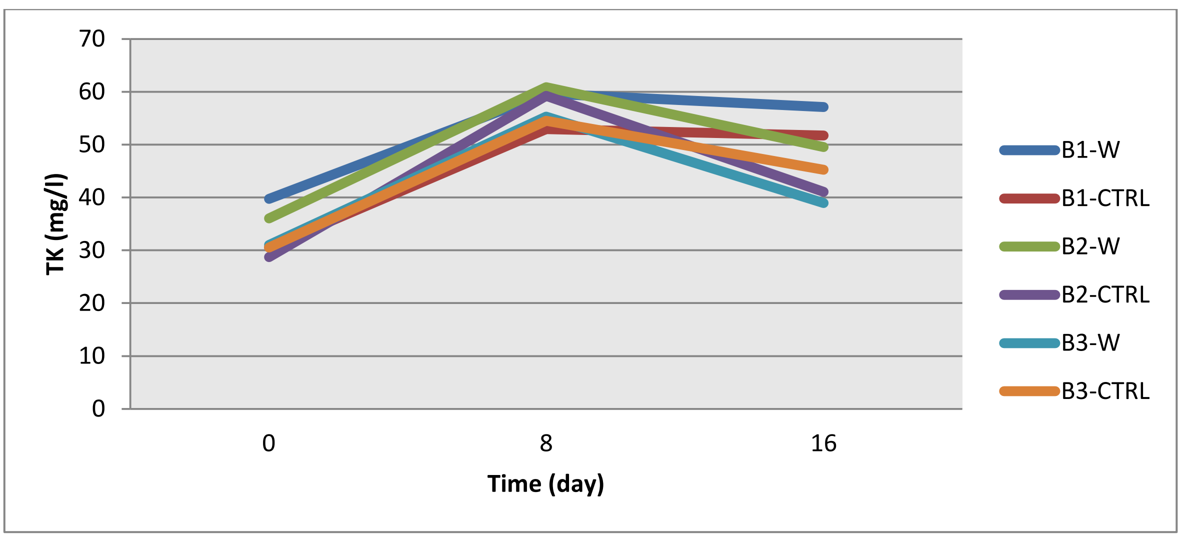

Figure 4.23: The Value of Total Potassium during Vermicomposting of Spent Coconut Flake.

Note: B1- SCF (100), B2-GM: SCF (30:70), B3- GM: SCF (50:50)
W- with worm, CTRL- without worm.

Additionally, the TK value in coconut shell also decreased at the final stage of vermicomposting. The TK of A1-W decreased from 42.74mg/l to 41.49 mg/l, in A2-W from 38.84mg/l to 37.25mg/l and in A3-W from 44.28mg/l to 32.73mg/l (Figure 4.21).

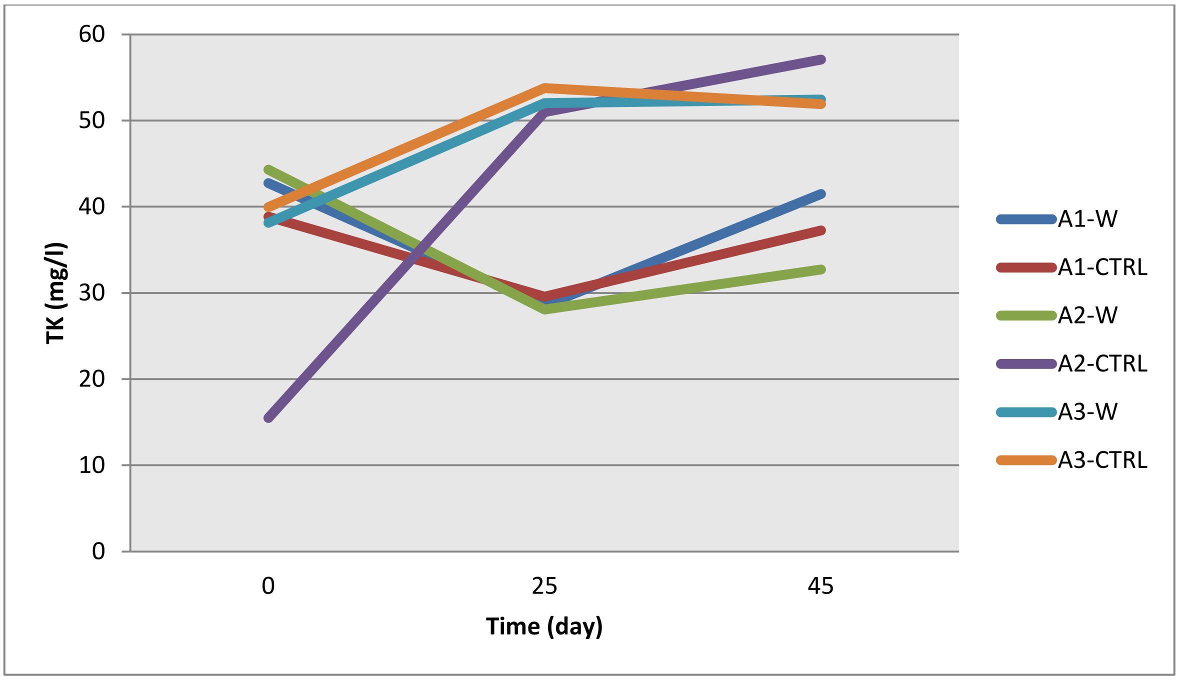

Figure 4.24: The Value of Total Potassium during Vermicomposting of Coconut Shell.

Note: A1- CS (100), A2-GM: CS (30:70), A3- GM: CS (50:50)
W- with worm, CTRL- without worm

The reduction of TK values in coconut husk and coconut shell experiments at final stage of vermicomposting were possibly due to the leaching of this soluble element by the excess water that drained through the mass. Similar scenario was reported by Elvira *et al* (1998); and Kaushik and Garg (2003). However, the TK value increased in spent coconut flake and the increase could be attributed to acid production during decomposition process by the microorganisms for solubilization of insoluble K. A similar scenario was addressed by Adi and Noor (2009); and Kaviraj and Sharma (2003). The TK values of spent coconut flake and coconut shell controls (without worms) at the final stage increased as in B1-CTRL from 28.73mg/l to 41.06mg/l. In B2-CTRL, it increased from 31.04mg/l to 38.95mg/l and in B3-CTRL from 30.55mg/l to 45.21. Additionally, the TK values also increased in coconut shell controls as in A1-CTRL from 15.50mg/l to 57.06, in A2-CTRL from 38.12mg/l to 52.44mg/l and in A3-CTRL from 39.95mg/l to 51.90mg/l. However, the TK values of coconut husk controls decreased at the final stage of vermicomposting as in C1-CTRL which declined from 41.06mg/l to 37.29mg/l. TK in C2-CTRL reduced from 37.93mg/l to 31.14mg/l while in C3-CTRL, it was from 44.06mg/l to 33.94mg/l. The increases in TK values of spent coconut flake and coconut husk controls were probably due to acid production during decomposition process by the microorganisms. But the reduction in TK values of coconut husk controls could be attributed to the leaching of potassium during the vermicomposting process.

Total Organic Carbon (TOC):

The TOC values of coconut husk experiments (with worms) decreased at the final stage of the vermicomposting (Table 4.7). The highest reduction of TOC was in C3-W (from 10.5% to 3.6%) and the lowest reduction in C1-W (from 4.9% to 3.5%).

Table 4.7: The Value of Total Organic Carbon during Vermicomposting of CH.

Experiment	TOC (initial) (%)	TOC (final) (%)
C1-W	4.9	3.5
C2-W	5.2	3.6
C3-W	10.5	3.6
C1-CTRL	7.9	3.9
C2-CTRL	7.612	3.7
C3-CTRL	11.7	3.3

Note: C1- CH (100), C2-GM: CH (30:70), C3- GM: CH (50:50)
W- with worm, CTRL- without worm.

For spent coconut flake, the TOC values in all of the experiments declined at the final stage of vermicomposting as shown in Table (4.8). The highest reduction of TOC value was in B1-W from 15.3% to 6.2% and the lowest reduction was in B3-W from 9.4% to 8.3%.

Table 4.8: The Value of Total Organic Carbon during Vermicomposting of SCF.

Experiment	TOC (initial) (%)	TOC (final) (%)
B1-W	15.3	6.2
B2-W	12.8	9.9
B3-W	9.4	8.3
B1-CTRL	15.3	8.3
B2-CTRL	15.9	8.9
B3-CTRL	11.6	6.7

Note: B1- SCF (100), B2-GM: SCF (30:70), B3- GM: SCF (50:50)
W- with worm, CTRL- without worm.

Similarly, the TOC values also reduced at the final stage of vermicomposting in all of the coconut shell experiments (Table 4.9).

Table 4.9: The Value of Total Organic Carbon during Vermicomposting of Coconut Shell.

Experiment	TOC (initial) (%)	TOC (final) (%)
A1-W	17.1	3.2
A2-W	15.7	3.6
A3-W	28.6	3.6
A1-CTRL	6.9	9.7
A2-CTRL	13.2	13.3
A3-CTRL	23.2	7.6

Note: A1- CS (100), A2-GM: CS (30:70), A3- GM: CS (50:50)
W- with worm, CTRL- without worm.

The highest reduction in TOC value of coconut shell was in A3-W from 28.6% to 3.6% and the lowest was in A2-W from 15.7% to 3.6%. The final reduction in TOC values of all types of coconut waste were possibly due to the rapid respiration that led to lose of TOC in terms of CO_2 or were probably due to the utilization of organic carbon by the worms and result in TOC reduction. Similar scenario was also reported by Ndegwa and Thompson (2000) and Karthikeyan (2007). Furthermore, the TOC reduction also could be attributed to the microorganism activities via enhancing respiration and decomposition process which resulted with carbon loss as CO_2. Same scenario was addressed by Suthar (2009).

The TOC value decreased at final stage of vermicomposting in coconut husk and spent coconut flake controls. The highest TOC reduction of coconut husk controls was in C3-CTRL from 11.7% to 3.3% and the lowest was in C1-CTRL from 7.9% to 3.9. For spent coconut flake, the highest TOC decrease was in B2-CTRL from 15.9% to 8.9% and the lowest was in B3-CTRL from 11.6% to 5.7%. However, the TOC value increased at the final stage in coconut shell controls (A1-CTRL and A2-CTRL), but TOC decreased in A3-CTRL. The TOC reduction in coconut husk and spent coconut flake controls was possibly due to degradation process by microorganism which resulted with carbon loss as CO_2. Same scenario was addressed by Suthar (2009).

- Total nitrogen (TN):

The TN values of coconut husk experiments (with worms) decreased at the final stage of the vermicomposting process (Table 4.10). The highest reduction of TN was in C3-W (from 0.79% to 0.37%) and the lowest reduction was in C1-W from (0.38% to 0.36%).

Table 4.10: The Value of TN during Vermicomposting of Coconut Husk.

Experiment	Total Nitrogen (initial) (%)	Total Nitrogen (final) (%)
C1-W	0.38	0.36
C2-W	0.41	0.38
C3-W	0.79	0.37
C1-CTRL	0.53	0.34
C2-CTRL	0.56	0.32
C3-CTRL	0.83	0.30

Note: C1- CH (100), C2-GM: CH (30:70), C3- GM: CH (50:50), W- with worm, CTRL- without worm.

For spent coconut flake, the TN value increased at the final stage in B2-W and B3-W from 0.394% to 0.556% and from 0.371% to 0.437, respectively. However, the TN value decreased in B1-W from 0.396% to 0.288% (Table 4.11).

Table 4.11: The Value of TN during Vermicomposting of Spent Coconut Flake.

Experiment	Total Nitrogen (initial) (%)	Total Nitrogen (final) (%)
B1-W	0.39	0.29
B2-W	0.39	0.56
B3-W	0.37	0.44
B1-CTRL	0.33	0.36
B2-CTRL	0.69	0.31
B3-CTRL	0.37	0.49

Note: B1- SCF (100), B2-GM: SCF (30:70), B3- GM: SCF (50:50)
W- with worm, CTRL- without worm.

The TN value of coconut shell declined at the final stage of vermicomposting in A1-W from 0.26% to 0.16%, while the TN values increased at the final stage in A2-W from

0.09% to 0.14 and in A3-W (1.16% to 0.17%) (Table 4.12). The reduction of TN values at final stage of vermicomposting in coconut husk experiments was possibly due to the mineralization of the nitrogen and the increase of pH in the final stage. These were assumed to be significant factors for losing nitrogen as volatile ammonia. Similar scenario was reported by Ndegwa and Thompson (2000).

Table 4.12: The Value of TN during Vermicomposting of Coconut Shell.

Experiment	Total Nitrogen (initial) (%)	Total Nitrogen (final) (%)
A1-W	0.26	0.16
A2-W	0.09	0.14
A3-W	1.16	0.17
A1-CTRL	0.50	0.45
A2-CTRL	0.33	0.37
A3-CTRL	0.29	0.36

Note: A1- CS (100), A2-GM: CS (30:70), A3- GM: CS (50:50)
W- with worm, CTRL- without worm.

The TN values increased at final stage in spent coconut flake and coconut shell experiments (except in A1-W) and could be attributed to the initial nitrogen level in the substrates and the mineralization process of nitrogen by microbial and enzyme activity in the gut of the worms. Same scenario was addressed by Asha *et al* (2006) and Tripathi and Bhardwaj (2004).

The TN values decreased at the final stage of vermicomposting in coconut husk controls. The highest reduction of TN value was in C3-CTRL from 0.83% to 0.30% and the lowest was in C1-CTRL from 0.53% to 0.34%. But, the final TN values of spent coconut flake and coconut shell controls increased (except in B2-CTRL and A1-CTRL). The increase of TN in spent coconut flake and coconut shell controls was probably due to the fact that the final level of TN depends on the initial value and the losses in organic carbon might also be responsible for nitrogen addition via decomposition process. Same scenario was reported by Kaviraj and Sharma (2003); and Garg and Renuka (2009).

- C-to-N ratio:

The C-to-N ratio decreased at the final stage of vermicomposting in coconut husk, spent coconut flake and coconut shell. The highest reduction of C-to-N ratio in coconut husk experiments was in C3-W (from 13.2 to 9.7) and the lowest reduction was in C2-W (from 12.6 to 9.5) (Table 4.13).

Table 4.13: C-to-N Ratio during Vermicompostin of Coconut Husk.

Experiment	C-to-N ratio Initial	C-to-N ratio Final
C1-W	12.7	9.5
C2-W	12.6	9.5
C3-W	13.2	9.7
C1-CTRL	14.9	11.4
C2-CTRL	13.5	11.3
C3-CTRL	14.1	10.9

Note: C1- CH (100), C2-GM: CH (30:70), C3- GM: CH (50:50)
W- with worm, CTRL- without worm.

For spent coconut flake, the highest reduction of C-to-N ratio was in B1-W (from 38.5 to 21.6), while the lowest reduction was in B3-W (from 25.3 to 18.9) (Table 4.14).

Additionally, the final C-to-N ratio in coconut shell also declined and the highest reduction was in A2-W (from 166.8 to 25.9), while the lowest reduction was in A3-W (from 24.5 to 20.6) as shown in Table 4.15.

Table 4.14: C –to-N Ratio during Vermicompostin of Spent Coconut Flake.

Experiment	C-to-N ratio Initial	C-to-N ratio Final
B1-W	38.5	21.6
B2-W	32.6	17.7
B3-W	25.3	18.9
B1-CTRL	45.8	22.9
B2-CTRL	22.7	29.0
B3-CTRL	31.2	13.6

Note: B1- SCF (100), B2-GM: SCF (30:70), B3- GM: SCF (50:50)
W- with worm, CTRL- without worm.

Table 4.15: C-to-N Ratio during Vermicompostin of Coconut Shell.

Experiment	C-to-N ratio Initial	C-to-N ratio Final
A1-W	64.9	22.9
A2-W	166.8	25.9
A3-W	24.5	20.6
A1-CTRL	13.8	21.3
A2-CTRL	39.9	35.7
A3-CTRL	80.7	21.1

Note: A1- CS (100), A2-GM: CS (30:70), A3- GM: CS (50:50), W- with worm, CTRL- without worm.

The reduction of C-to-N ratio at the final stage of vermicomposting of coconut husk, spent coconut flake and coconut shell were possibly due to the decline of TOC via degradation process in the form of CO_2 and decrease of TN and release as volatile ammonia throughout the vermicomposting process. Similar scenario was addressed by Tripathi and Bhardwaj (2004). The C-to-N ratios were within the acceptable range for vermicompost which was addressed by EPA that preferable C-to-N ratio is lower than 20:1 (Adi and Noor, 2009). The role of C-to-N for cell synthesis, growth, and metabolism is important in all living organisms. To provide proper nutrition for earthworms during vermicomposting, carbon and nitrogen must be present in the substrates at the correct ratio. Moreover, the final C-to-N ratio declined in the control set-ups of all types of coconut waste (except in B2-CTRL and A1-CTRL which increased). The highest reduction of C-to-N ratio in coconut husk controls was in C1-CTRL from 14.9% to 11.4% and the lowest in C2-CTRL from 13.5% to 11.3%. For spent coconut flake, the C-to-N ratio declined in B1-CTRL from 45.8% to 22.9% and B3-CTRL from 31.2% to 13.6%. Additionally, the C-to-N ratio of coconut shell controls decreased in A2-CTRL from 39.9% to 35.7% and A3-CTRL from 80.7% to 21.1%. The reduction of C-to-N ratio in all types of coconut waste control set-ups was possibly due to the reduction of TOC via respiration process in the form of CO_2.

- <u>Multiplication of Earthworms (Weights and Numbers) in Different Experiments:</u>

After 50 days of vermicomposting of coconut husk, the highest earthworm weight gain was in C1-W (3.39 ± 0.71g) and the lowest weight gain was in C2-W (0.03 ± 1.4g). The number of earthworms declined at the final stage of vermicomposting and the highest reduction was in C1-W (9.0 ± 2.0), while the lowest reduction was in C3-W (4.0 ± 3.0) as shown in Table 4.16.

Table 4.16: Multiplication of Earthworms (Weights and Numbers) of Coconut Husk.

Experiment	plot	Weight of earthworms (g)		Earthworms weight gain (g)	Earthworms weight gain (g)	Number of earthworms		Earthworms number gain
		Initial	Final			Initial	Final	
Coconut Husk	C1-W-1	22.9	14.5	+3.05	3.39 ± 0.71	20	10	-10
	C1-W-2	22.9	16.8	+4.21		20	11	-9
	C1-W-3	22.6	17.6	+2.91		20	13	-7
	C2-W-1	28.0	11.7	+0.90	0.03 ± 1.4	20	9	-11
	C2-W-2	25.2	17.2	+0.82		20	13	-7
	C2-W-3	26.3	18.1	-1.62		20	15	-5
	C3-W-1	21.2	15.4	+2.68	2.53 ± 2.4	20	12	-8
	C3-W-2	15.4	nd	nd		20	nd	nd
	C3-W-3	17.6	18.1	+4.90		20	15	-5

Note: C1- CH (100), C2-GM: CH (30:70), C3- GM: CH (50:50), W- with worm.

For spent coconut flake, the highest weight gain was in B2-W (7.67 ± 1.6g) and the lowest was in B1-W (1.99 ± 0.2g).

The number of the worms declined at the final stage of vermicompostin of spent coconut flake. The highest reduction in worm numbers was in B1-W (8.0±2.0) and the lowest decline in worm numbers was in B3-W (4.0±1.0) as shown in Table 4.17. Furthermore, the highest weight gain of the worms in coconut shell was in A3-W (3.5 ± 1.6g) and the lowest weight gain was in A1-W (1.55 ± 0.5g). The final number of the worms also reduced in coconut shell and the highest reduction was in A1-W (9.0±1.0), while the lowest was in A3-W (7.0±2.0) (Table 4.18).

Table 4.17: Multiplication of Earthworms (Weights and Numbers) of Spent Coconut Flake.

Experiment	plot	Weight of earthworms (g)		Earthworms weight gain (g)	Average earthworms weight gain (g)	Number of earthworms		Earthworms number gain
		Initial	Final			Initial	Final	
Spent coconut flake	B1-W-1	30.5	18.7	+1.93	1.99 ± 0.2	20	11	-9
	B1-W-2	30.1	21.4	+1.83		20	13	-7
	B1-W-3	31.5	22.7	+2.22		20	13	-7
	B2-W-1	25.5	23.8	+5.95	7.67 ± 1.6	20	14	-6
	B2-W-2	21.5	24.1	+9.05		20	15	-5
	B2-W-3	22.7	27.3	+8.01		20	17	-3
	B3-W-1	31.0	27.6	+2.80	6.03 ± 2.9	20	16	-4
	B3-W-2	30.2	32.6	+6.93		20	17	-3
	B3-W-3	31.1	31.7	+8.37		20	15	-5

Note: B1- SCF (100), B2-GM: SCF (30:70), B3- GM: SCF (50:50)
W- with worm.

Table 4.18: Multiplication of Earthworms (Weights and Numbers) of Coconut Shell.

Experiment	plot	Weight of earthworms (g)		Earthworms weight gain (g)	Average earthworms weight gain (g)	Number of earthworms		Earthworms number gain
		Initial	Final			Initial	Final	
Coconut Shell	A1-W-1	38.6	22.9	+3.61	2.12 ± 2.7	20	10	-10
	A1-W-2	45.5	28.8	+3.77		20	11	-9
	A1-W-3	48.4	25.6	-1.02		20	11	-9
	A2-W-1	36.7	27.1	+1.41	1.55 ± 0.5	20	14	-6
	A2-W-2	38.6	30.1	+1.15		20	15	-5
	A2-W-3	36.0	18.3	+2.10		20	9	-11
	A3-W-1	41.5	24.5	+1.67	3.5 ± 1.6	20	11	-9
	A3-W-2	34.0	24.3	+3.90		20	12	-8
	A3-W-3	34.1	28.7	+4.83		20	14	-6

Note: A1- CS (100), A2-GM: CS (30:70), A3- GM: CS (50:50), W- with worm.

The final earthworm weight gains were possibly due to the availability of adequate nutrient in the vermibeds for the worms particularly inside the mixture of waste with GM. Moreover, GM also probably played an important role in earthworm weight gain via providing more nutrients. Additionally, the earthworms also could utilize microorganisms in their substrates as the food source and can digest them selectively. Similar scenario was reported by Suthar (2009); and Singh and Sharma (2002).

The final number of the worms decreased in all types of coconut waste. The reduction of the worm's number was possibly due to the change of pH, because this type of earthworm is very sensitive to pH change. Also, the texture and hardness of the waste might have an impact on the worms' reproduction. In addition, the decrease in worm numbers was probably due to the high level of protein that can cause rapid disrepair and heating which often result in fatal conditions. This scenario had been addressed by Adi and Noor (2009).

4.4 A Comparison Between Different Types of Coconut Wastes

The comparison between the different types of coconut waste was carried out based on the criteria to assess the success of the process and to determine which type of coconut wastes decomposed better. These criteria were the time required for complete degradation and which mixture gave better results in terms of physico-chemical parameters.

Spent coconut flake (SCF) was showed to be the fastest waste type that could be degraded i.e. within 16 days. On the other hand, coconut shell took more than 50 days for total decomposition. Additionally, the size and chemical structure of the waste material showed to be the main factors that impact the time required for the degradation process. Hence, lower content of lignin and fibre or smaller particle size in spent coconut flake might have fastened the degradation rates. Additionally, among all the experiments (C2, B2 and A2), which contained GM: CS, SCF and CS (30:70) seemed to be the best mixture in terms of the quality of the vermicompost, physico-chemical parameters and the survival of the earthworms.

4.5 Conclusion

This study has inferred that coconut waste can be decomposed to nutrient rich by-product via vermicomposting as a potential alternative. The vermicompost can be utilized as an organic fertilizer instead of being disposed of in landfills. The results also showed that the smaller the size of the shredded waste, the sooner it could be decomposed. This type of the worm (*Eudrillus euginea)* could actively decompose the coconut waste and gain weight in most of the experiments, yet the number of the worms might have declined.