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SUSTAINABLE CAMPUS: SOLID WASTE MINIMISATION USING VERMICOMPOSTING

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Abstract: A newly constructed Puncak Alam Campus of Universiti Teknologi MARA (UiTM) embarked upon sustainable campus initiatives. One of the initiatives was to incorporate waste reductions into the solid waste management using vermicomposting. Laboratory scale tests were conducted to evaluate the vermicomposting of food waste. The expected outcome of the study was to come up with full scale vermicomposting design. The focus of the study was be the food waste, as it constitutes the highest composition of solid waste from the campus. Earthworms species selected were the Africa Night Crawler (*Pudrilus eugeniae*) due to its aggressiveness. Two types of bedding (cow dung and sewage sludge) were used due to their availability at site. Food waste reductions were found to be almost 100% after 7 days. The end products of earthworms' casts were found to have high nutrients contents (N, P, K), thus suitable for use as organic fertiliser. The results of the laboratory scale tests enable improvement to be made to the full scale vermicomposting bin design. This will enable full scale implementation of waste reduction initiative as part of the sustainable campus initiatives.

Keywords: Solid waste management, sustainable campus, vermicomposting, waste minimisation.

Introduction

Managing municipal solid waste (MSW) is a challenge in most developing countries, including Malaysia. Improvement in the standard of living due to economic growth has increased consumption, which in turn has increased municipal solid waste generation. The generation rate for Malaysia is about 30,000 tonnes per day (Agamuthu, 2007). For big cities, like Kuala Lumpur and Penang, the average generation rate is 1.30 kg/capita/day. This is consistent with the finding of Nasir (2002) for the state of Selangor, which has the generation rate of 1.26 kg/capita/day. In terms of composition, organic waste, paper and plastic are found to be the main composition of municipal solid waste in Malaysia. The highest composition is organic (from food waste), which constituted 40% to 50% of the municipal solid waste (Fauziah & Agamuthu, 2005, Fauziah & Agamuthu, 2007, Fauziah & Agamuthu, 2009, Agamuthu *et al.*, 2009, Zamali *et al.*, 2009). In Balakong, the composition is even higher at 69% (Abu Samah *et al.*, 2013). This study however, focused mainly on campus solid waste generation. For campus waste, Universiti Teknologi MARA Shah Alam campus and Puncak Alam campus generated about 2,070 kg per day and 1425 kg per day of food waste, respectively (Mohd Rashid, 2011).

Municipal solid waste management involves waste collection from points of generation, transportation and disposal. In Malaysia, the common method of disposal is by landfill (Agamuthu, 2013). There are about 170 landfills in Malaysia, but unfortunately only 10% can be classified as sanitary landfills (Chan *et al.*, 2007). Therefore, most of the municipal solid wastes are dumped into non-sanitary landfills, which have inadequate cover, leachate management and gas management. As a result, pollution is released to surrounding air, surface water and groundwater (Chan *et al.*, 2007).

Apart from the shortcomings of the disposal sites, the practices of disposing all municipal solid waste to landfills or dumpsites are also not sustainable. Municipal solid waste in Malaysia consisted of 45% organic waste and 17% recyclables (Agamuthu & Hansen, 2007). There have been reduction in recyclables being disposed due to promotion of 3R (reduce, reuse, recycle) by the local authorities in Malaysia (Agamuthu & Fauziah, 2014). However, composting is still not being practiced in Malaysia even though most of the organic wastes have the potential to be composted. Agamuthu & Hansen (2007) believed that implementation of composting has the potential of reducing the municipal solid waste disposed and thus prolonged the lifespan of the landfills. Furthermore, composting has the potential for commercialisation of end products. Therefore, composting has the potential to enhance environmental sustainability of the landfills with the added economic benefits of commercialising the end products. Nevertheless, the efforts towards composting are still lacking despite its potential benefits (Mohd Sharir *et al.*, 2010). Victor & Agamuthu (2013) recommended a more integrated approach based on policy to overcome the challenges of managing municipal solid waste.

There are various methods of composting. This study however will focus only on vermicomposting. Vermicomposting is the processing of organic wastes through certain species of earthworms to enhance the process of waste conversion and produce better end product, which is the vermicompost (Shahzad, 2014). The earthworms and the microorgansims act symbiotically involving bio-oxidation and stabilisation of organic materials in aerobic condition. Earthworms ingested organic matter and fragmented them into fine particles by passing them through its gizzard and later produce sanitised, deodorised and textured humus in the form of castings (Datar *et al.*, 1997; Ndegwa *et al.*, 2000; Shahzad, 2014; Sinha *et al.*, 2010). These casts are ready-to-use fertiliser that can be used at higher application rate than conventional compost, since nutrients are released at plants' preferred rates. Vermicomposting can be used to compost household and garden waste and reduce solid waste generation at source (Fauziah & Agamuthu, 2009).

Earthworms casts are found to be suitable as fertilisers by various researchers (Basheer & Agrawal, 2013; Bhadauria *et al.*, 2014). As the

Figure 1: Windrow (Source: Munroe, 2007)

Figure 2: Bin type (Source: Mohd Rashid, 2011)

Table 1: Types of earthworms and physical properties (Source: Datar *et al.*, 1997)

Types of Earthworms	Red Earthworm (*Lumbricus Rubellus*)	Tiger Earthworm (*Eisenia foetida*)	Blue Earthworm (*Perionyx Excavatus*)	African Night Crawler (*Pudrilus eugeniae*)
Pictures				
Length (mm)	35-100	50-100	4-100	150-200
Diameter (mm)	3-5	1-5	1-3	3-5

end product will be used as organic fertiliser, monitoring of nutrient is important (Dominguez & Gomez-Brandon, 2013; Islas-Espinoza *et al.*, 2014). Therefore, in this study, nutrients contents of vermicompost will be compared against commercial fertiliser.

There are various systems of vermicomposting. Examples of vermicomposting systems are shown in Figures 1 and 2. The system include: Windrow (Batch/ Continuous/ Wedges), Bed or Bins (Top-fed bed/ Stacked Bin), or Reactors.

One of the main components of vermicomposting is the earthworms. Some of the species used for vermicomposting include Red Earthworm (*Lumbricus Rubellus)*, Tiger Earthworm (*Eisenia foetida),* Blue Earthworm (*Perionyx Excavatus*) and African Night Crawler *(Pudrilus eugeniae)*. Table 1 shows the Red earthworm (*Lumbricus Rubellus*), the external structures of Tiger Earthworm (*Eisenia foetida),* the physical properties of the various species of earthworms, the Blue Earthworm species (*Perionyx Excavatus)*, and the African Night Crawler (*Pudrilus eugeniae*). Julianus (2010) found that the African Night Crawler was the most effective compared to the other species, which was consistent with findings of Datar *et al.* (1997). Furthermore, African Night Crawlers (*Pudrilus eugeniae*) are ferocious eater of organic food which active in digestion process (Datar *et al.*, 1997). Thus, in this study, the African Night Crawler (*Pudrilus eugeniae*) was adopted as the composter.

Some of the suitable bedding materials include: shredded paper; shredded corrugated cardboard; peat moss; commercial worm bedding; animal dung and ground coffee. As this study in principle was to promote sustainable campus, readily available materials were adopted. Cow dung was readily available from adjacent properties. Sewage sludge was also readily available from the Campus Sewage Treatment Plant. Thus, cow dung (as applied by Garg & Gupta, 2010; Rai & Singh, 2013) and sewage sludge (as applied by Yang *et al.*, 2013) were used as bedding materials. In this study, the combined bedding of sewage sludge and cow dungs as applied by Kizilkaya & Türkay (2014) was not used. Instead, the performance using the two types of bedding separately will be compared.

The objective of this study is to evaluate vermicomposting method for Puncak Alam Campus of Universiti Teknologi MARA (UiTM), Malaysia. The end product (compost) can be used for landscape plants within the campus. The outcome of this study would be a design of vermicomposting bin to be used in UiTM Puncak Alam campus as part of its sustainable campus initiatives.

Materials and Methods

The vermicomposter used was a laboratory scale set-up to test the viability of solid waste reduction using vermicomposting. The methodology adopted was based on studies by Garg & Gupta (2010). Figure 3 shows the methodology adopted in this study. The parameters used to measure the performance of the vermicomposting system include: waste reduction capacity, growth of earthworms over specific time, optimum ratio using two different types of bedding materials, and comparison of nutrient contents of the compost produced compared to commercial fertiliser.

The first component of the vermicomposter was the earthworms. The vermicomposter adopted was African Night Crawler (*Pudrilus eugeniae*) (as shown in Table 1) based on findings by Garg & Gupta (2010) and Julianus (2010).

The second component was the feedstock. In this study, the feedstock was mainly organic food waste. The location adopted was UiTM Campus in Puncak Alam, Selangor, Malaysia.

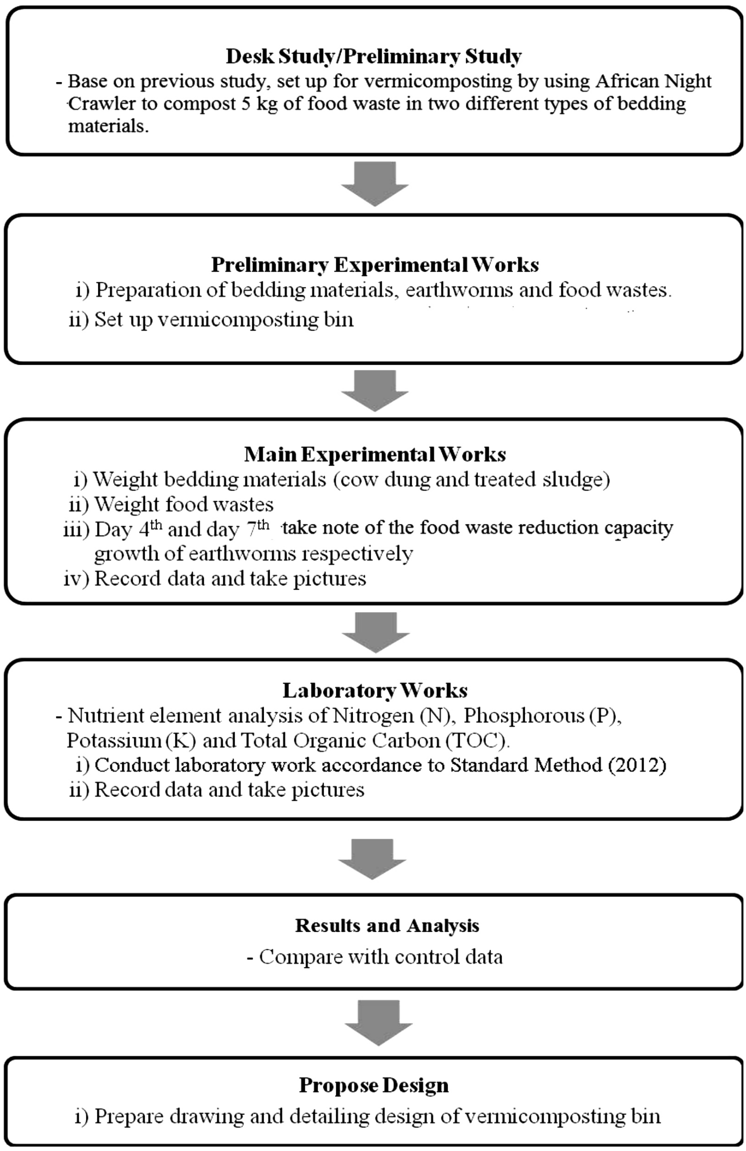

Figure 3: Vermicosting method

This campus was adopted because it was recently opened and being a new campus, new management of solid waste can be easily introduced. This campus has an area of 329 750 km^2, and had 6,000 staffs and students (Mohd Rashid, 2011). At the campus, there are 19 cafeterias and eateries. Each one generated about 75 kg/day of organic food waste. Figure 4 shows the process of shredding the feedstock to simulate the campus cafeteria's food waste. No pre-treatment was applied and food waste was in the dry conditions.

Figure 4: Shredding of feedstock

The third component was the bedding materials. In this study, cow dung and sewage sludge were adopted. Figure 5 shows the preparation of bedding materials, the filter and the loading of food waste. Figure 6 shows the isometric view of the vermicomposting bin. The detail dimensions of the vermicomposter are shown in Figure 7. Aerobic condition was maintained throughout the study by the provision of 5mm diameter holes at 60mm c/c spacing all along the width and the length of the bin (as shown in Figure 7).

The performance evaluation involved three tests for each types of bedding materials. Each test was conducted over a 7-day period of composting to determine the performance in terms of waste reduction capacity and growth rate of the earthworms. Table 2 shows the mass

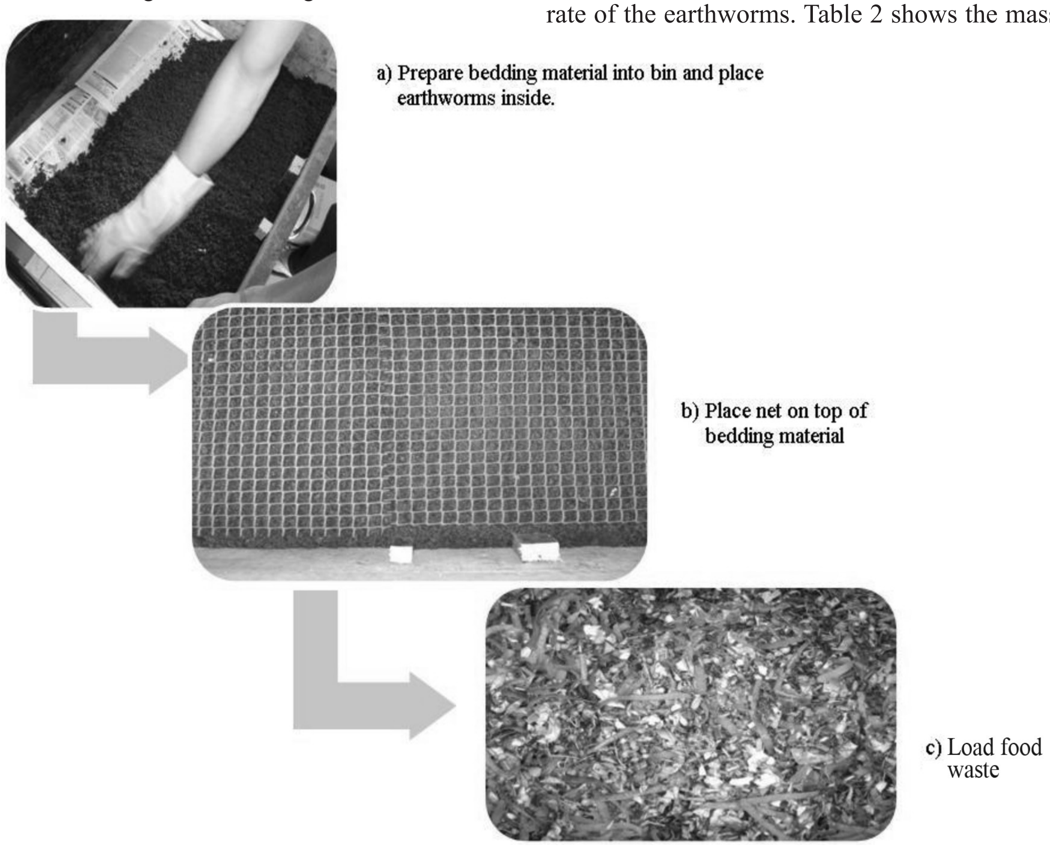

Figure 5: Preparation of the vermicomposting bin

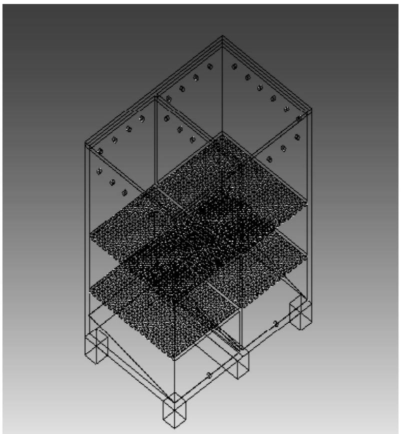

Figure 6: Vermicomposting bin

ratio used (earthworms: bedding: food waste) for both types of beddings. The tests denoted as T_1, T_2 and T_3 used cow dung as the bedding material. Sewage sludge was used for tests T_4, T_5 and T_6.

There were several limitations of this study. This study only used the African Night Crawler (*Pudrilus eugeniae*) species. Food wastes that were offensive to the African Night Crawler (*Pudrilus eugeniae*) such as meat, dairy products, egg, oily foods, salt and vinegar (Julianus, 2010) were omitted to avoid the African Night Crawler (*Pudrilus eugeniae*) from leaving the vermicomposting bin.

Results and Discussion

The parameters monitored include: comparison of food waste reduction between cow dung and

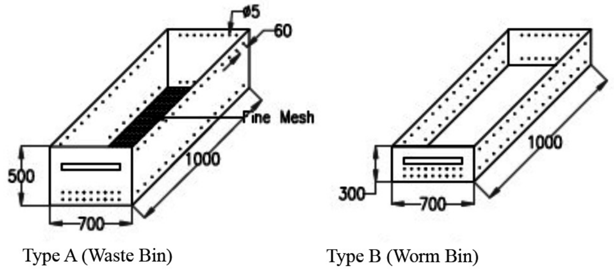

Figure 7: Vermicomposting Dimensions

sewage sludge bedding; earthworm growth for both beddings; comparison of end product (vermicompost) in terms of nutrient contents (nitrogen, phosphorus, potassium and total organic carbon) for both beddings; and finally the recommendation of vermicomposting bin design.

Figure 8 shows the comparison of food waste reduction between the two types of beddings (cow dung and sewage sludge). Tests T1, T2 and T3 represented cow dung bedding, and T4, T5 and T6 represented sewage sludge bedding.

The percentage reductions of food waste for cow dung bedding were observed to be higher during the early stage, where percentage reduction of all three tests exceeded 50%. On the 4th day, T1 achieved the highest percentage reduction of 60%. On the 7th day, T3 achieved the highest percentage reduction of 88%. Despite some slight difference between the three tests, there were no significant differences between the three ratios. Similar trend was

Table 2: Ratio used in the vermicomposting for 6 tests

Test	Earthworm (kg)	Bedding Material (kg)	Food Waste (kg)	Ratio
Cow Dung				
T_1	1.0	2.5	5.0	1:2.5:5
T_2	1.0	3.0	5.0	1:3.0:5
T_3	2.0	6.0	5.0	2:6.0:5
Treated Sludge				
T_4	1.0	2.5	5.0	1:2.5:5
T_5	1.0	3.0	5.0	1:3.0:5
T_6	2.0	6.0	5.0	2:6.0:5

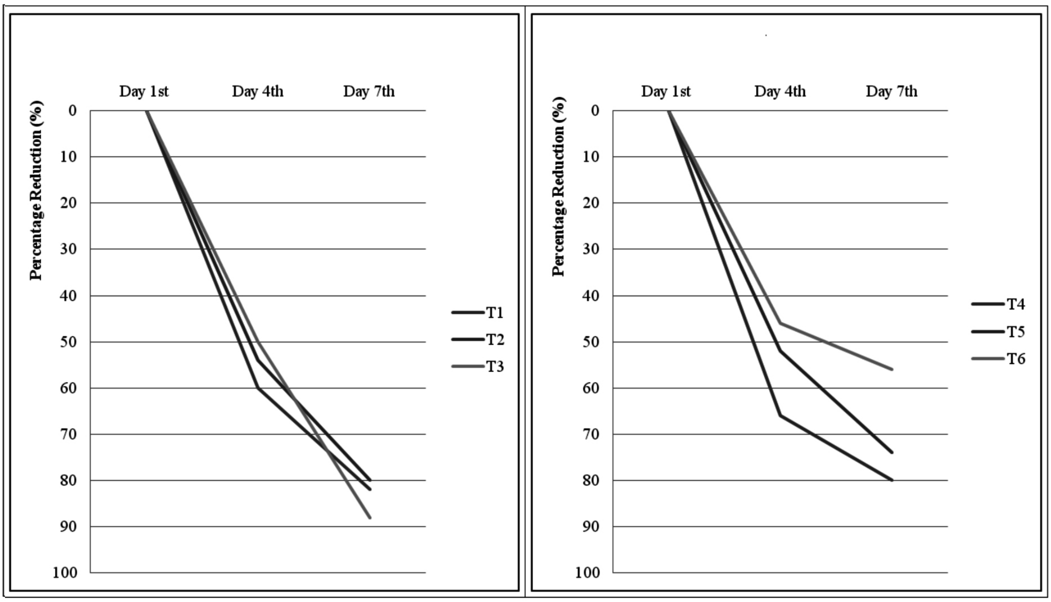

Figure 8: Food waste reduction

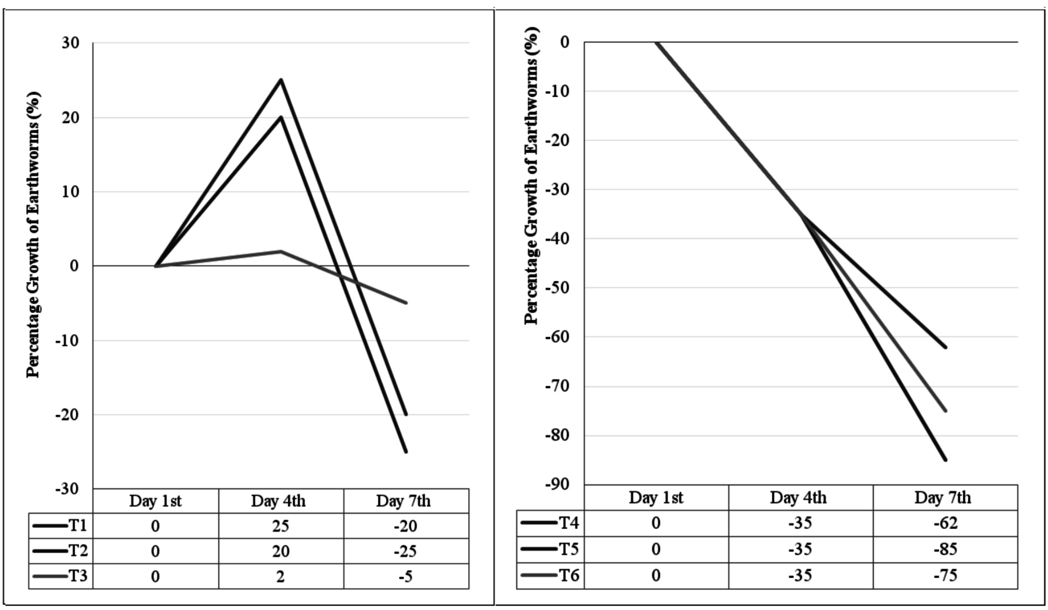

Figure 9: Growth of earthworms

observed for sewage sludge bedding as per cow dung bedding with higher early reductions. Nevertheless, the quantities were different and there were differences between the three ratios for sewage sludge bedding. The highest food waste percentage reduction was achieved by T4, with 66% and 80% reductions after 4 days and 7 days, respectively. The lowest food waste percentage reduction was achieved by T6, with 46% and 56% reductions after 4 days and 7 days, respectively. Early reductions were due to earthworms' active consumption of abundant food.

Figure 9 shows the comparison of the growth of earthworms between cow dung bedding and sewage sludge beddings. For the growth of earthworms, differences in trend were observed between cow dung bedding and sewage sludge bedding.

The weight of earthworms for cow dung bedding increased until the 4th day and then decreased until the 7th day. On the 4th day, the percentage increases were 25%, 20% and 2%, for T1, T2 and T3, respectively. The increase was due to increase in the microorganisms that provided suitable nutrient sources (Dominguez *et al*., 2000; Ndegwa *et al*., 2000). However, on the 7th day, the percentage increases were -20%, -25% and -5%, respectively. Earthworms in all tests have reduced growth on the 7th day. The reductions were due to reduction in food source due to consumption, as no food wastes were added during the 7-day vermicomposting process (Dominguez *et al*., 2000; Ndegwa *et al*., 2000). However, earthworms' biomass increased due to castings produced by earthworms creating organic fertiliser in the form of vermicompost (Adi & Noor, 2009).

The earthworms' growth for sewage sludge bedding reduced throughout the test period. All ratios (T4, T5 and T6) reduced by 35% after 4 days. The earthworms' weights further reduced after 7 days by 62%, 85% and 75% for T4, T5 and T6, respectively. The highest reduction was observed for T5, where most of the earthworms left the vermicomposting bin. According to Adi & Noor (2009), some earthworms were dead in the bin due to high moisture contents, which led to anaerobic conditions.

Figures 10 and 11 show the comparison between waste reduction and earthworms' growth for cow dung bedding and sewage sludge bedding, respectively. These figures show the relationship between waste reduction and earthworms' growth.

Figure 10 shows that the reduction in food waste increased with the increase in percentage growth of earthworms over the first four days. T1 recorded the highest food waste reduction and the highest growth of earthworms. More than 50% of food wastes were reduced in all T1, T2 and T3. The high reduction was due to the presence of food waste and cow dung bedding, which provided suitable carbon: nitrogen (C:N) ratio for earthworms to enhance the vermicomposting process (Edward & Bohlen, 1996; Dominguez *et al*., 2000; Adi & Noor, 2009). However, between the 4th and the 7th day, the growth rate of earthworms reduced due to food waste reduction and higher population of earthworms (due to growth for the first 4 days). These trends of reduced growth rate within crowded earthworms' population due to food limitations were also observed by Datar *et al*. (1997), Ndegwa *et al*. (2000) and Dominguez & Edwards (1997).

Figure 11 shows that for sewage sludge bedding, the increase in food waste reductions resulted in the decrease in the growth of earthworms. T4 had the highest food waste reduction rate, and had the least reduction in earthworms' growth. In T5 and T6, by the end of the tests, most of the earthworms either left the bin or dead, due to unsuitable conditions in the bin for earthworms, such as high moisture contents and anaerobic conditions (Adi & Noor, 2009).

Nutrients analyses were conducted to assess the suitability of the end product as organic fertiliser. Figures 12, 13 and 14 show the comparison between cow dung bedding and sewage sludge bedding for Nitrogen, Phosphorus and Potassium (N, P, K), respectively. The organic contents of the end products are shown in Figure 15, where Total Organic Carbon contents were measured.

Figure 12 shows that T4 and T5 (sewage sludge bedding) had significantly higher nitrogen contents compared to T1 and T2, for ratios 1 and 2, respectively. T3 (cow dung bedding) had slightly higher nitrogen contents compared to T6 for ratio 3. Overall, nitrogen contents in sewage sludge bedding were observed to be higher than those for cow dung bedding. The highest nitrogen content was found in T4 (sewage sludge bedding). Suthar & Singh (2008) found that the increased amount of nitrogen in

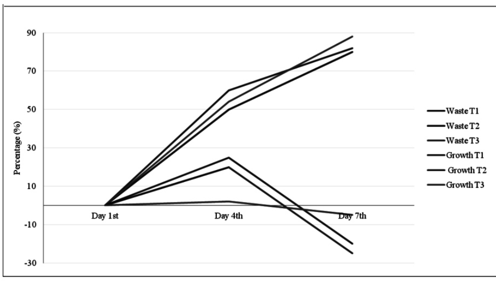

Figure 10: Cow dung bedding

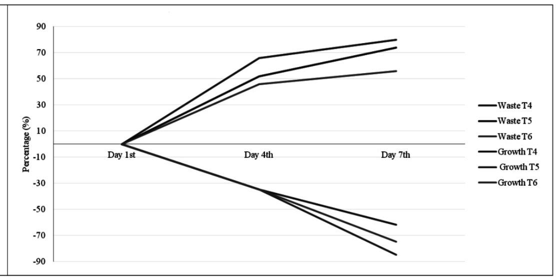

Figure 11: Treated sewage sludge bedding

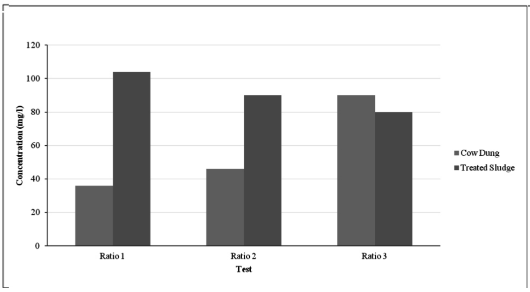

Figure 12: Nitrogen contents

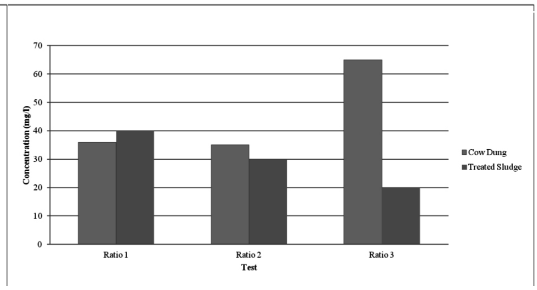

Figure 13: Phosphorus contents

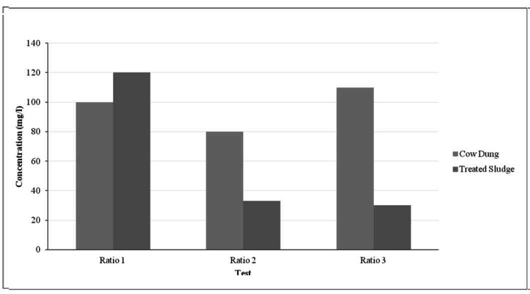

Figure 14: Potassium contents

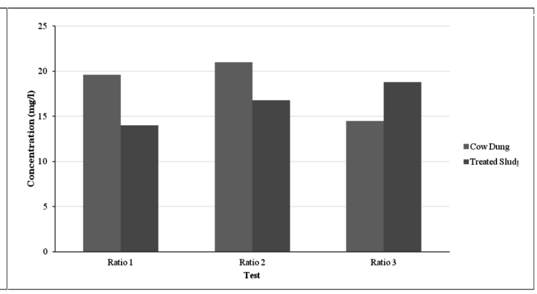

Figure 15: Total organic carbon contents

vermicompost was due to earthworms mediated nitrogen mineralization of wastes. Furthermore, nitrogenous metabolic products of earthworms which were returned to the soil through casts, urine, muco-proteins and earthworm tissue also increased the nitrogen contents. Thus, the mixture of vegetable waste and sewage sludge produced vermicompost with high nitrogen contents, which was consistent with the findings of Muthukumaravel *et al.* (2008).

Figure 13 shows that T1 had slight lower phosphorus contents compared to T4 for ratio 1, but T2 had slightly higher phosphorus contents compared to T5 for ratio 2. T3 however, had significantly higher phosphorus contents compared to T6, for ratio 3. Overall, phosphorus contents in cow dung bedding were higher than those of sewage sludge bedding. The highest phosphorus content was found in T3 (cow dung bedding). Ndegwa *et al*. (2000) found that the increase in phosphorus content might be due to higher phosphorus content in the wormcasts. However, low concentration of phosphorous may be due to occurrence of anaerobic condition which resulted from increase of moisture content and limitation of air flow.

Figure 14 shows that T1 had lower potassium contents compared to T4, for ratio 1. However, T2 and T3 had significantly higher potassium contents compared to T5 and T6, for ratios 2 and 3, respectively. Overall, phosphorus contents in cow dung bedding were higher than those of sewage sludge bedding. However, the highest potassium content was found in T4 (sewage sludge bedding). The increase in potassium contents in vermicompost after completion of the composting process were also found by Adi & Noor (2009).

The nutrients analyses of N, P and K indicated that all three nutrients increased in the end products of both types of beddings. Thus, the end products were suitable to be used as fertilizer.

Total Organic Carbon TOC was expected to reduce in the end products. Figure 15 shows that T1 and T2 had higher TOC contents compared to T4 and T5, for ratios 1 and 2, respectively, and thus lower TOC reductions. However, T3 had lower TOC contents compared to T6, thus higher TOC reductions. Overall, cow dung bedding had lower TOC reductions compared to those of sewage sludge bedding. Generally, organic carbon content was expected to decrease during the vermicomposting process (Kale & Bano, 1988, Kaushik & Garg, 2003). Suthar & Singh (2008) found that earthworms modified the substrate conditions, affected carbon losses from the substrate through microbial respiration in the form of carbon dioxide. They found that carbon losses may also due to mineralization of organic matter.

Table 3 shows the comparison between nutrient analysis of vermicompost and commercial fertilizer. One sample of the vermicompost was selected as a representative sample. In comparison with the chemical fertilizer, it was found that compost product had lower concentration for each parameter tested. According to Kaviraj & Sharma (2003), acid production during organic matter decomposition by the microorganisms is the major mechanism for solubilisation on insoluble Phosphorus (P) and Potassium (K).

The laboratory scale set-up was able to produce satisfactory results. Food waste reductions were observed for both cow dung and sewage sludge beddings, with cow dung bedding showing slightly better reductions. Earthworms' growths were observed to be more satisfactory for cow dung bedding, compared to sewage sludge bedding. Nevertheless, both shown reduction in growth when food waste supplies were limited, thus food waste supplies need to be continuous rather than one-off as simulated in the tests. The nutrients contents indicated some mixed results between cow dung bedding and sewage sludge bedding. Organic contents reduced as expected for both types of beddings. The results obtained were also consistent with other researchers. In general, despite some differences, both types of beddings can be used in the vermicomposting process.

The expected outcome of this study was to provide the design of vermicomposting bin to be used for full scale implementation at Puncak Alam campus of Universiti Teknologi MARA (UiTM). The results from the laboratory scale indicated that the configuration used was viable as vermicomposter for Puncak Alam Campus. Thus, the results from the laboratory scale will be used to configure and design the full scale vermicomposting bin.

The laboratory scale tests found that the earthworms will crawl out of the bin to find their food. As a result, the bins were designed in two levels to separate food waste and bedding material. The vermicomposting bin was designed with seven (7) compartments in two (2) levels to receive wastes daily over a one-week operation. Each compartment (level 1) was designed to cater for organic waste with the capacity of 100 kg. Each compartment (level 2) was designed to load earthworms and bedding materials for this system. The Bin for level 1 was designed with dimensions of 0.7 m (L) x 1.0 m (W) x 0.5 m (D). The Bin for level 2 was designed with dimensions of 0.7 m (L) x 1.0 m (W) x 0.3 m (D). The base of bin for level 1 was covered with screens (sieve) to allow earthworms to pass through it while crawling up to food wastes in level 1. By separating food wastes (level 1) and bedding (level 2), introduction of new food wastes in level 1 during subsequent

Table 3: Nutrient element analysis of the compost product

	Vermicompost	Commercial Fertilizer
TOC (mg/l)	19.70	18.87
Nitrogen (mg/l)	5.75	70.00
Phosphorus (mg/l)	0.04	216.30
Potassium (K) (mg/l)	235.50	256.20

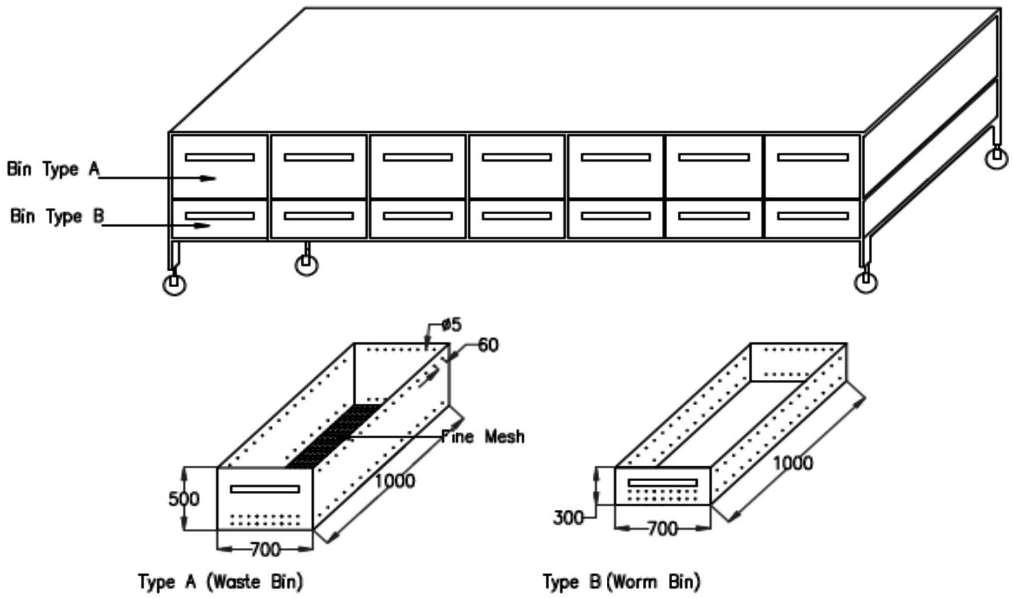

Figure 16: Vermicomposting bin

weeks will not disturb the bedding materials. Thus, earthworms' environment would not be disturbed. They can simply crawl up to eat and return to the comfort of the bedding in level 2. The bottom of bins at level 2 was also covered with screens (sieve) of smaller size openings to stop earthworms from leaving the bin. In order to avoid excessive moisture content and anaerobic conditions, which had caused mortality and exodus in the laboratory scale tests, holes were provided at the bottom of Bin at level 2 for drainage and aeration purposes.

The bin was strengthened by structural frames, which was fitted with rollers on each leg (as shown in Figure 16). This will make the bin mobile and allow the operators to change the location of the bin. Each small bin (two types, one type for level 1 and one type for level 2) was also fitted with rollers to enable the bin to be pulled out and pushed in with ease. The Bins were designed as a batch system, with 7 days cycle. Each cycle was designed to decompose 100 kg of food wastes at level 1, and 10 kg of earthworms (African Night Crawler) to be placed in bedding material at level 2. The site selected was adjacent to the Sewage Treatment Plant, therefore, the most readily available bedding materials would be sewage sludge. By utilizing sewage sludge, the sustainable campus initiatives will also reduce sludge to be disposed from the campus. Thus, double waste reductions can be achieved (solid waste and sewage sludge). Figure 16 shows the proposed design of the vermicomposting bin for full scale applications at UiTM Puncak Alam Campus.

Conclusion

The objective of the study was achieved where vermicomposting was found to be effective in food waste reduction. For the laboratory scale tests, almost 100% of food wastes were composted after 7 days. However, growth of earthworms suffered reductions due to food limitations, high moisture contents and anaerobic conditions. For the laboratory scale tests, the most effective ratio was found to be 2:6:5 (food waste: earthworms: bedding). As for the end products (casts), nutrients contents increased indicating suitability as organic fertiliser. Lessons learned from the laboratory scale tests were incorporated into the full scale vermicomposting bin design with food waste loading of 100 kg/day. Thus, the expected outcome of full scale vermicomposting bin design was also achieved. The full scale design will enable Puncak Alam campus of UiTM to implement the waste reductions as part of its sustainable campus initiatives.

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