Research Journal of Agriculture and Forestry Sciences _________________________________ ISSN 2320-6063
Vol. **4(1),** 1-13, January **(2016)** *Res. J. Agriculture and Forestry Sci.*

Vermicomposting Efficiency and Quality of Vermicompost with Different Bedding Materials and Worm Food Sources as Substrate

Manaig Elena M.
College of Agriculture, Laguna State Polytechnic UniversitySiniloan Campus, Siniloan, Laguna, PHILIPPINES
elena_manaig@yahoo.com

Available online at: www.isca.in, www.isca.me
Received 11th November 2015, revised 23rd December 2015, accepted 6th January 2016

Abstract

Vermicomposting is a simple environment-friendly technology that supportssustainable agriculture and waste management programs. Itinvolves physical and biochemical action of earthworms in converting organic materials (usually wastes) into two useful products- the earthworm biomass and high quality organic fertilizer, the vermicompost. The efficiency of vermicomposting may be measured by the worm number and/or biomass and the vermicompost produced. To achieve high efficiency one of the keys is selection of proper substrate which is composed of bedding material and food source for the worms. A 3x3 factorial experiment with plant matter and animal manures as the factors was conducted to determine the efficiency of vermicomposting as indicated by worm biomass vermicompost produced. Data on worm number and weight, and vermicompost produced were collected and analyzed. A sample of vermicompost from each treatment was brought to soil laboratory for NPK analysis. It showed that the sawdust, among the plant materials, and hog manure, among the animal manures were the bestmaterials for vermicomposting substrate. The worm numberand total weight were highest in this combination. The individual weight and concentration of nutrients NPK were highest in G. sepium and chicken manure substrate. It is concluded that efficiency of producing worms and vermicompost is affected by the substrate materials and that it could be increased by selecting appropriate substrates.

Keywords: Substrate, Vermicomposting Efficiency, Biomass, Bedding, Food Source.

Introduction

Vermicomposting is a simple environment-friendly technology that supports sustainable agriculture and waste management programs. It has been encouraged in the Philippines even before the issuance of Republic Act No. 10068 (Organic Agriculture Act of the Philippines) of 2010. It is now the primary component of the National Organic Agriculture Program which was formulated under said law. Almost all of the existing organic farms and sustainable agriculture programs in the country have vermicomposting as part of their systems.

Vermicomposting involves physical and biochemical action of earthworms in converting organic materials (usually wastes) into two useful products- the earthworm biomass and high quality organic soil conditioner, the vermicompost. The physical action includes substrate mixing andl oosening, maintaining aerobic condition and actual grinding. The biochemical action is the breakdown of the substrate by beneficial microorganisms in the earthworm's gut. The goals of vermicomposting are to continually increase the number and weight of worms and to convert the substrate material into vermicompost in the shortest time and highest recovery as possible[1].With the useful products, vermicomposting can be engaged in by farmers as source of extra income.

The technology, therefore, gives twofold benefits-producing good quality organic fertilizer, and reducing the volume of organic waste by converting it into bioactive rich soil fertilizer-conditioner. Vermicompost enriches soil with microorganisms[2]; soils with vermicasts have roughly 1000 times more beneficial bacteria than soil without worms[3,4]. It enhances germination, plant growth and crop yield; improves soil texture and structure, nutrient retention, water-holding capacity, and aeration[2]. It is of better quality than conventionally produced compost in terms of physical and nutritional characeristics, and many other possible products can be derived from worms such as vermi-meal, and from vermicompost such as vermitea and vermiwash.

The vermicompost promotes plant growth from 50-100% over conventional compost and 30-40% over chemical fertilizers[5]. In addition to providing soil organic carbon and NPK, vermicompost also provides enzymes and hormones which stimulate plant growth. It enhances soil biodiversity by promoting the beneficial microbes which, inturn, enhances plant growth, plant health and crop yield by producing growth-regulating hormones and enzymes, controlling plant pathogens, nematodes and otherpests[3]. Wastes are degraded by over 75% faster than conventional systems and compost produced are cleansed of harmful microorganisms and toxic substances, and enriched with nutrients and beneficial soil microbes[5].

Vermicomposting efficiency is measured by the worm number and biomass produced and by the vermicompost yield in a certain period of time. To get the maximum efficiency of vermicomposting, the compost worms must be provided with the five basic things that they need. These are favorable living environment, usually called "bedding"; food source; correct moisture of the substrate (not too low, not too high); adequate aeration; and protection from too high or too low temperatures[4].

Since moisture holding capacity and aeration are characteristics of bedding, in general, the selection of bedding materials is a key to successful vermiculture or vermicomposting. Worms can be highly productive (and reproductive) if conditions are favorable; however, their efficiency drops off rapidly when their basic needs are not met. Good bedding mixtures are an essential element in meeting those needs. They maintain the correct level and consistency of moisture, provide adequate aeration for the supply of oxygen, and protect the worms from too high or too low temperatures[4]. Fortunately, the materials that can be used for good bedding mixtures are generally available and mostly abundant in the farm and even in the backyard and households. It is suggested that selection of substrate materials is a key to efficient vermicomposting process[6]. This study aimed at finding the plant materials and animal manure combination that will result in higher efficiency of vermicomposting.

Different organic materials that can be used as bedding have different characteristics. The same is true with materials that can be used as food source for the worms. The differences can affect directly the reproduction and growth of worms, and the amount of substrate that can be broken down by worms into compost. The bedding materials should provide a hospitable environment and the food source, nutrition for the worms. In this study it was hypothesized that the different substrates (bedding material+food source) will affect the efficiency of producing worms and compost.

Materials and Methods

Materials: The plant materials used that served primarily as beddingwere rice (O*ryza sativa*) straw, *Gliricidia sepium* (madre cacao) leaves and sawdust. Rice straw is a cheap source of organic fertilizer. It contains entire elements taken up by the rice plant. In burning rice straw, traditionally practiced in the Philippines, some of the phosphorus (P), potassium (K) and sulfur (S), and almost all nitrogen (N) are lost. Aside from adding pollution to the environment, burning, also kills beneficial soil microorganisms directly through heat and indirectly by removing their food source. The *G. Sepium* leaves can be converted into vermicompost that is high in microbial diversity and nutrient content, with the use of worms[8]. Sawdust is a main organic waste of sawmill. It has a variety of practical uses including as mulch, and as soil amendment. This material takes many years for decomposition because of high C:N ratio (400:1), high contents of lignin, tannin and resin[7]. Improperly managed sawdust may accumulate and emit harmful leachates into local water and river systems and cause pollution[6].

For animal manures, chicken manure, cattle dung and hog manure were used to serve primarily as food source. These are three of the most common feed stocks that can provide good nutrition to worms[4,8]. These wastes can be efficiently converted to vermicast and vermicompost. Livestock farming wastes such as cattle, pig and chicken manures make excellent feedstock for earthworms[9].

Breeder stock of *Eudrilus euginiae* procured from the Vermiculture and Vermicomposting Project of Laguna State Polytechnic University, Siniloan Campus was used.*Eudrilus eugeniae* is an earthworm species indigenous in Africa but it has been bred extensively in the USA, Canada, Europe and Asia for the fish bait market, where it is commonly called the African night crawler[10]. This epigeic species of earthworm is adapted under tropical condition and the most commonly used in the Philippines[8]. In the studyin India and Australia on the action and composting abilities ofthree species of earthworms, namely, *Eisenia fetida, Eudrilus euginae and Perionyx excavates* on cattle dung, raw food wastes and garden wastes, they found that the worm *Eudrilus euginae* was the best waste degraderfollowed by *Eisenia fetida*[11]. *E. eugeniae* is a fast-growing and productive earthworm in animal waste[12].

Figure-1
Breeder stock of *Eudrilus euginiae*

A total of 27 worm boxes each measuring 1.0 x 0.5 x 0.15 m was used. This size of box could accommodate more than 5 kg substrate with depth of about 10 cm. A 7.5 cm to 10 cm depth of substrate is optimum for vermicomposting as this would allow for enough aeration and release of heat[8].

Methods: Experimental Design: A3x3 factorial experiment was performed in 27 vermiboxes to test the efficiency of vermicomposting in different bedding materials (Factor A) and worm food source (Factor B). Factor A levels were rice straw, *G. sepium* leaves and sawdust. Factor B was composed of cattle manure, chicken manure and hog manure. Nine treatments, each with three replications, were used and distributed in a completely randomized design. Each treatment was a combination of one plant material and one animal manure.

Combinations of each of the bedding materials with each of the food sources made up the experimental substrates and served as treatments. Each treatment was replicated three times. The proportion of bedding material to food source of 3:2 was used in all combinations. The combinations of bedding material and worm food used in the experiment are shown in table-1.

Table-1
The combinations of bedding material and worm food used in the experiment

Treatment	Combination	Abbreviation
T_1	rice straw and cattle manure	RS-CaM
T_2	rice straw and chicken manure	RS-ChM
T_3	rice straw and hog manure	RS-HM
T_4	*Gliricidia sepium* leaves and cattle manure	GSL-CaM
T_5	*Gliricidia sepium* leaves and chicken manure	GSL-ChM
T_6	*Gliricidia sepium* leaves and hog manure	GSL-HM
T_7	sawdust and cattle manure	SD-CaM
T_8	sawdust and chicken manure	SD-ChM
T_9	sawdust and hog manure	SD-HM

Preparation of the substrate: The rice straw and air-dried *G. sepium* leaves were shredded first with the use of shredding machine and the sawdust was used as collected. As suggested smaller size of the feed particles is favorable to worm action and also provides more surface area per volume, which facilitates microbial activities as well as moisture availability[13,14]. The three animal manures were air-dried and pounded into small pieces before mixing with the plant materials. The bedding materials and the food source were mixed at 3:2 ratio. The mixtures based on the designed combinations were placed in plastic sacks and pre-decomposed for 15 days under shade of trees. Though earthworms can process many different organic materials and yield high-quality vermicompost, it is better to use pre-composted organic wastes for worms for faster action and production ofcompost. The pre-decomposed waste is an ideal medium for the worms to act on[15]. The mixing and pre-composting of the substrates was done in two batches- the first at 15 days before the start of the experiment and the second, at 30 days after the first. After the 15-day pre-composting, the substrates were stirred and air-dried for one day to dissipate heat.

Experimental set-up: The experiment was conducted for two months from February to April 2013 at the Bioorganic Building, Laguna State Polytechnic University, Siniloan Campus. The experimental area was enclosed with coconut leaves and used fish nets as protection from temperature extremes and from predators such as birds. The 5-kg substrate (mixture of pre-decomposed bedding material and food source) was put inside the box and sprayed with water to moisten it. At the time of loading, 100-g worms were placed into each box. For the first 30 days all the replicates were fed with 5 kg substrate loaded in each box. Since a worm can eat for one day an amount approximately its body weight, the 5-kg substrate for one month was used to provide an allowance of 166.67 grams/day.

With the use hand sprayer, the mixed substrate was sprayed on the surface with water every day or whenever drying was observed. This was to maintain moisture at approximately 60-70%. Moisture was tested by hand-squeeze method. A lump of substrate is squeezed by hand and when a drop of water went out of the mass, the moisture is correct.

After one month the worms were separated from the substrate and the vermicompost was pushed to one side of the box giving enough space for another batch of feedstock to be loaded. Then second batch of 5 kg of pre-decomposed substrate was loaded into each box. The worms were then returned to the box after counting and weighing them. They were placed on the newly loaded substrate. The experimental set-up is shown in Figure-2.

Data collection: The weight of worms loaded to each box was set all at 100 g. This was the biomass (weight) at Day1. Before loading on the substrate, the numberof worms in 100-g weight was determined and served as the worm number at Day 1. At 30 daysand 60 days of vermicomposting, the total worm biomass was determined by weighing and the number by counting the individual worms of any size. The worms were first taken from the substrate by hand, and the substrate materials were gently removed. To facilitate removal of the adhering material on the earthworm body, the hands are moistened first. Data on the increase in number and weight were obtained by subtracting the initial measurements from the measurements at Day 30 and at Day 60. The data were collected and recorded by replication.

At the end of the experiment (Day 60), the uncomposted potion of the substrate was separated from the composted part. The harvested vermicompost was then mixed thoroughly and then air-dried for one day. The air-dried weight was determined. The time of harvesting was based on the recommendation that vermicompost should be harvested when most of the materials have been consumed by the worms[8]. The pre-digested material will be converted into quality vermicompost within 30 days[15]. Given the optimum conditions of temperature (20-30°C) and moisture (60-70%), about 5 kg of worms (numbering approximately 10,000) can vermiprocess 1 ton of organic wastes into vermicompost in just 30 days and the process becomes faster with time[6].

Statistical analysis: All of the collected data from three replicates of each treatment were analyzed. Mean for three replicates was used as descriptive tool. Two-way analysis of variance (ANOVA) with replicationwas used to test for significant differences and Tukey's test for pairwise comparison. This analysis was done for worm number and increase in number; weight and increase inweight, vermicompost yield, and dry matter weight of harvested vermicompost and the amounts of nitrogen (N), phosphorus (P) and potassium (K).

Results and Discussion

Number of worms: The mean numbers of worms and increments are shown in table-2 with comparison indicated by letters. Results of ANOVA are presented in table-3. The initial number of worms had no significant differences. At Day 30 and Day 60, the cumulative worm numbers were consistently highest in sawdust and lowest in *G.sepium* leaves.

At Day 30 no significant difference was observed between the worm numbers in hog manure and cattle manure which were both higher than the number in chicken manure. At Day 60, the worm numbers were significantly different among the three manures- highest in hog manure followed by cattle manure and lowest in chicken manure. This result conforms to the report that vermicompost made with hog manure outperformed all other vermicomposts, as well as commercial fertilizer as found by scientists of Ohio State University[4]. This implies the superiority of hog manure as part of the substrate in vermicomposting. The next highest number was with cattle manure. In an experiment conducted, the researchers reported that *E. euginiae* had reproduction rate coon/worm/day) of 1.42 ± 0.009 in cow dung mediumand the hatching percentage was 82 ±1.15. This means a single adult worm produced 34 hatchlings in 30 days in cow dung[16].

Results of the present study showed that number of worms was highest in sawdust among the plant materials and in hog manure among the animal manures at Day 60. The lowest numbers were in *G. sepium* leaves and in chicken manure. Accordingly, the SD-HM combination gave the highest number of worms and the GSL-ChM gave the lowest number of worms. The next highest worm population was in SD-CaM substrate. *G. sepium* leaves have a high feeding value; its crude protein is 20-30% of the dry matter[17]. However, the high temperaturein the substrate resulting fromits rapid degradation due to high protein/N levels could create conditions that are fatal to the worms 4. This is also true with chicken manure. It has N content of 5.1% compared to pig manure with 2.68% and cattle manure with 2.06%[18]. The lower numbers of worms in these two materials was due to mortality caused by the high temperature resulting from rapid degradation due to high N contents of the substrate. Dead worms were observed in GSL-ChM boxes especially in the initial loading. Turning the substrate was done to dissipate heat.

Figure-2
The experimental set-up

Increase in number of worms: At Day 60, the worm population in sawdust was more than 4.6 times the original number with an increase of 343.8%; in rice straw it was 216.19% and in *G. sepium* leaves, 81.73%. The increase in worm number in SD-HM substrate was 521.36%which is significantly highest compared with the increases in other treatments. This was followed by the increase in SD-CaM combination. The lowest increase was observed in GSL-ChM substrate. It was noted that the substrates with *G. sepium* leaves and with chicken manure had increases in worm number lower than the increases in substrates without these materials. At Day 60, there was significant interaction effect of the plant material and animal manure. This signifies that there are plant materials and animal manures that combine well with each other and there are those that do not make good combination.

Table-2
Number of worms and increase in the number of worms

Treatment	**Mean Number of Worms**			**Increase in number**			**Percent Total Increase, %**
	Day 1 (Initial No.)	Day 30	Day 60	Day 1 to Day 30	Day 30 to Day 60	Day 1 to Day 60	
Factor 1: Plant material							
Rice straw	105	243^{b}	332^{b}	138^{b}	89^{ab}	227^{b}	216.19^{b}
G. sepium leaves	104	135^{c}	189^{c}	31^{c}	54^{b}	85^{c}	81.73^{c}
Sawdust	105	329^{a}	466^{a}	224^{a}	137^{a}	361^{a}	343.80^{a}
Factor 2: Manure							
Cattle manure	104	249^{a}	330^{b}	145^{a}	82	226^{b}	217.30^{b}
Chicken manure	105	170^{b}	242^{c}	64^{b}	72	136^{c}	129.52^{c}
Hog manure	105	288^{a}	414^{a}	184^{a}	126	309^{a}	294.29^{a}
Factor combination							
T_1 (RS-CaM)	103	242^{bc}	362^{c}	139^{bc}	120^{b}	259^{c}	251.46^{c}
T_2 (RS-ChM)	107	158^{cd}	241^{e}	51^{cde}	83^{b}	134^{e}	125.23^{e}
T_3 (RS-HM)	105	328^{ab}	392^{bc}	223^{ab}	64^{b}	287^{c}	273.33^{c}
T_4 (GSL-CaM)	102	137^{d}	192^{fg}	34^{de}	55^{b}	89^{fg}	87.25^{fg}
T_5 (GSL-ChM	104	120^{d}	164^{g}	16^{e}	44^{b}	60^{g}	57.69^{g}
T_6 (GSL-HM)	106	149^{cd}	211^{ef}	43^{cde}	62^{b}	105^{ef}	99.06^{ef}
T_7 (SD-CaM)	107	368^{a}	438^{b}	260^{a}	70^{b}	330^{b}	308.41^{b}
T_8 (SD-ChM)	105	231^{bc}	319^{d}	126^{cd}	88^{b}	214^{d}	203.81^{d}
T_9 (SD-HM)	103	388^{a}	640^{a}	285^{a}	252^{a}	537^{a}	521.36^{a}

Treatment means in the same column with the same letter are not significantly different.

Table-3
Results of ANOVA for worm population

Variable	Source of Variation	F-value	P-value	Difference
Initial number of worms	Plant Material (A)	0.26	0.775	Not significant
	Animal Manure (B)	0.27	0.767	Not significant
	Interaction (AxB)	1.42	0.266	Not significant
Worm number at Day 30	Plant Material (A)	37.99	0.000	Highly significant
	Animal Manure (B)	14.78	0.000	Highly significant
	Interaction (AxB)	2.55	0.075	Not significant
Worm number at Day 60	Plant Material (A)	109.26	0.000	Highly significant
	Animal Manure (B)	42.52	0.000	Highly significant
	Interaction (AxB)	10.32	0.000	Highly significant
Increase in number from Day 1 to Day 30	Plant Material (A)	38.65	0.000	Highly significant
	Animal Manure (B)	15.41	0.000	Highly significant
	Interaction (AxB)	2.63	0.069	Not significant
Increase in number from Day 30 to Day 60	Plant Material (A)	5.16	0.017	Significant
	Animal Manure (B)	2.44	0.115	Not significant
	Interaction (AxB)	4.18	0.014	Significant
Total increase in number from Day 1 to Day 60	Plant Material (A)	117.58	0.000	Highly significant
	Animal Manure (B)	46.46	0.000	Highly significant
	Interaction (AxB)	11.65	0.000	Highly significant

Worm weight: The experiment started with uniform weight of worms (100 g) so that only the increases in weight were analyzed. The mean weights and weight increases are shown in Table 4. The mean total worm weight increases in 60 days were the same for rice straw and sawdust but both were significantly higher than the mean weight increase in *G sepium* leaves. High bulking potential, absorbency and carbon:nitrogen ratio are desirable characteristics of worm beddings[4]. Rice straw and sawdust have these characteristics. On the other hand, the leaves of *G. sepium* dry easily and had low porosity. Low worm counts in *G. sepium* leaves were recorded and hence lower worm biomass.

The increase in worm weight in substrates with rice straw and sawdust were highest compared with the weight increase in substrates without these materials. This higher increase of worm weight was due to the greater worm counts. Likewise, the lower weight increment in substrates with *G. sepium* leaves was due to lower worm counts. This result matches the result of an experiment that showed an increase in the growth of individual earthworms at lower population density but greatest overall earthworm biomass production at the highest population density[19]. The greater biomass in substrates with rice straw and sawdust was due to the greater number of worms. There was an inverse relationship between population density and the growth rates of individual worms. In 60-day experiment of composting floral and market wastes with *E. eugeniae*, the total biomass gain was found to be 1456.6 grams or 2171.4%[20]. The result of the present study conforms to the result of experiment using *E. fetida* where the worm growth in growing-finishing pig solids and sow pig solids was faster than in either separated cattle solids or pre-compostedcattle solids[21]. It could be explained that the different weight increases and growth rates of worms in vermicomposting could be due to the difference in substrate quality or due to fluctuating environmental conditions[22].

The increase in total biomass was significantly higher in treatments without *G. sepium* leaves in the substrate. The lower biomass with *G. sepium* leaves was due to the lower worm counts. As explained earlier, the high nitrogen content and faster drying of *G. sepium* leaves caused a condition that is unfavorable to the reproduction of worms. The lower increase in worm weight was due to lower worm population.

Individual worm weight: The average individual worm weights are also shown in Table 4. In the present study, the individual weight of worms at the start of the experiment ranged at 0.93-0.98 g. This was within the range reported that *Eudrilus* populations from 14 different locations within Lagos State in Nigeria had average weight ranges from 0.45 g to 1.26 g and below the weight range of 3-4g for the Indian counterparts[23]. At Day 30, there were significant differences among individual weights of worms in rice straw, *G. sepium* and sawdust. For manures, no significant differences were observed. At Day 60, the individual worm weights were the same in rice straw and *G. sepium* leaves and significantly lowest in sawdust. For the animal manures, that of chicken gave the significantly higher individual worm weight compared with worm weight in cattle manure and hog manure. The individual worm weights are shown in Table 4.

The data on worm numbers showed that the worm counts were highest in sawdust and hog manure. Because the experimental boxes were of the same dimensions, greater number of worms means higher density. The mean weights of *E. eugeniae* increased with lower density and higher densities resulted in lower individual weight gain[24]. In this study, the correlation between the worm number and individual weight at Day 60 was highly significant (r=0.893, p=.001). In a related study it was also observed that worms fed on any nitrogen-rich diet grew faster than those with little nitrogen available[25]. Apart from density, another reason why individual worm weight was higher in *G. sepium* and chicken manure is the higher nutrient content especially protein or nitrogen since the growth of oligochaetes is relatively proportional to nutritional level.The quality of the available food determines the growth of earthworm and the N content is a major factor that affects the biomass gain[26]. The worm biomass growth varies inversely with C:N ratio of worm food which means biomass decreased as the C-to-N ratio of the feed increased[27,11]. Sawdust has the highest C:N ratio among the three plants materials used in this study. Also, in a study of vermicomposting kitchen waste, garden waste, newspaper, hair and eggshell, it was shown that that earthworm's growth is dependent on nature of feed material[1].

Quality of Vermicompost: The results of assay of vermicompost for NPK contents are shown in table-6. On air-dry and oven-dry bases, the highest percentages ofN and K contents were noted in GSL-ChM substrate. The SD-ChM combination gave the highest %P on oven-dry basis. In terms of total of NPK contents, the treatments with highest percentages were SD-ChM and GSL-ChM combinations

The concentration of N was highest in GSL-ChM and lowest in SD-HM. On the other hand, the amounts of P and K were both highest in SD-ChM and lowest in RS-CaM. This is because sawdust has higher C:N ratio compared to rice straw and *G. sepium* leaves. At higher C-to-N ratio, concentration of P is also high[27]. Excretory products, mucus, body fluid, enzyme and even decaying tissue of the death earthworms are associated with the higher level of N in vermicompost[13]. A related study revealed that vermicomposting increased the concentration of nitrate-nitrogen to 28-fold after 17 weeks, while in conventional compost there was only 3-fold increase[20].

In an experiment using *Eisenia fetida,* cattle dung has been found to yield the most nutritive vermicompost compared with vermicompost from grass, aquatic weed and municipal solid waste[28]. This is contrary to the findings in an experiment that nitrogen (N) content (%) is low in cow dung compost and higher in *Vitex negundo* and *Parthenium composts*. It was cited that the mixture of plant waste and cow dung is suitable for the production of higher quality vermicompost when compared with composting the same components individually[29]. It was explained that whatever is the substrate used, the NPK content of vermicompost is higher than the NPK of farmyard wastes[20]. This was in accordance with the finding that plant matter had reduced C and increased N after having been vermicomposted[30]. Findings of this study is supported by the statement that along with other factors, the nutritional quality of vermicompost is determined primarily by the type of the substrate (raw materials) used for composting[28].

Table-7 shows the NPK contents (in grams) of the harvested vermicompost. This shows an important comparison since the moisture content was not uniform upon air-drying which implies that different substrates have different water holding capacities. In this study, *G. sepium* leaves showed poorer moisture retention. The dry matter of sawdust and rice straw were the same and these two gave significantly higher dry matter than *G. sepium* leaves. Dry matter differed significantly among the three animal manures, highest in hog manure and lowest in chicken manure.

On oven-dry basis, the amounts of N in harvested vermicompost were significantly different among the three plant materials-highest in *G. sepium* leaves and lowest in sawdust. Although the vermicompost yield in *G. sepium* leaves was lowest, it gave the highest amount of N. *G. sepium* leaves have a high feeding value, with crude protein comprising 20-30% of the dry matter which is equivalent to 3.2% to 4.8% nitrogen[17]. The P amount with sawdust was significantly higher compared with P amounts in *G.sepium* leaves and rice straw. For potassium content, it was not significantly different between sawdust and *G.sepium* leaves but significantly lower with rice straw. Parallel with this result is the analysis of vermicomposts produced from four different weeds that showed different contents of N, P and K[30]. Although the vermicompost yield of SD-ChM substrate ranked only third in terms of dry matter content, it ranked first in terms of N, K and to N+P+K contents and second in terms of P content. The N content RS-CaM vermicompost was also at highest rank. The lowest amounts of N were in SD-HM and SD-CaM substrates. In general the substrates with cattle manure gave the lowest amounts of P, K and total NPK.

Table-4
Weight and increases in the weight of worms at stocking, after 30 days and after 60 days

Treatment	Weight of worms			Increase in weight			Individual weight of worms		
	Day 1 (Initial)	Day 30	Day 60	Day 1 to Day 30	Day 30 to Day 60	Day 1 to Day 60	Day 1 (Initial)	Day 30	Day 60
Factor 1: Plant material									
Rice straw	100	213.60	311.22	113.60[a]	97.62	211.22[a]	0.9519	0.9305[b]	0.9965[a]
G. sepium leaves	100	160.10	203.00	60.10[b]	42.90	103.00[b]	0.9602	1.1812[a]	1.0742[a]
Sawdust	100	209.27	277.92	109.27[a]	68.65	177.92[a]	0.9516	0.6635[c]	0.6456[b]
Factor 2: Manure									
Cattle	100	190.52	257.72	90.52[ab]	67.20	157.72	0.9597	0.8532	0.8419[b]
Chicken	100	166.76	249.84	66.76[b]	83.08	149.84	0.9492	1.0308	1.0836[a]
Hog	100	225.70	284.59	125.70[a]	58.89	184.59	0.9548	0.8911	0.7908[b]
Factor combination									
T_1 (RS-CaM)	100	214.33	310.62	114.33	96.29	210.62[a]	0.9680	0.8833	0.8627
T_2 (RS-ChM)	100	182.54	302.45	82.54	119.91	202.45[a]	0.9382	1.1572	1.3058
T_3 (RS-HM)	100	243.93	320.59	143.93	76.66	220.59[a]	0.9494	0.7511	0.8211
T_4 (GSL-CaM)	100	152.93	207.01	52.93	54.08	107.01[bc]	0.9783	1.1186	1.0796
T_5 (GSL-ChM)	100	136.52	177.23	36.52	40.71	77.23[c]	0.9588	1.1361	1.0759
T_6 (GSL-HM)	100	190.86	224.78	90.86	33.92	124.78[bc]	0.9436	1.2888	1.0671
T_7 (SD-CaM)	100	204.29	255.52	104.29	51.23	155.52[ab]	0.9328	0.5577	0.5834
T_8 (SD-ChM)	100	181.22	269.85	81.22	88.63	169.85[ab]	0.9507	0.7992	0.8690
T_9 (SD-HM)	100	242.31	308.39	142.31	66.08	208.39[a]	0.9713	0.6334	0.4843

Treatment means in the same column with the same letter are not significantly different.

Table-5
Results of ANOVA for worm weights

Variable	Source of Variation	F-value	P-value	Difference
Worm weight at 30 days, grams	Plant Material (A)	4.53	0.025	Significant
	Animal Manure (B)	4.50	0.026	Significant
	Interaction (AxB)	0.03	0.998	Not significant
Worm weight at 60 days, grams	Plant Material (A)	26.51	0.000	Highly significant
	Animal Manure (B)	2.97	0.083	Not significant
	Interaction (AxB)	0.59	0.672	Not significant
Increase in weight from Day 1 to Day 30, grams	Plant Material (A)	4.53	0.025	Significant
	Animal Manure (B)	4.50	0.026	Significant
	Interaction (AxB)	0.03	0.998	Not significant
Increase in weight from Day 30 to Day 60, grams	Plant Material (A)	1.91	0.177	Not significant
	Animal Manure (B)	0.38	0.686	Not significant
	Interaction (AxB)	0.20	0.934	Not significant
Total increase in weight from Day 1 to Day 60, grams	Plant Material (A)	26.51	0.000	Highly significant
	Animal Manure (B)	2.87	0.083	Not significant
	Interaction (AxB)	0.59	0.672	Not significant
Individual worm weight at Day 1, grams	Plant Material (A)	0.25	0.781	Not significant
	Animal Manure (B)	0.28	0.756	Not significant
	Interaction (AxB)	1.42	0.268	Not significant
Individual worm weight at Day 30, grams	Plant Material (A)	20.17	0.000	Highly significant
	Animal Manure (B)	2.63	0.099	Not significant
	Interaction (AxB)	2.04	0.132	Not significant
Individual worm weight at Day 60, grams	Plant Material (A)	17.09	0.000	Highly significant
	Animal Manure (B)	8.02	0.003	Highly significant
	Interaction (AxB)	2.12	0.121	Not significant

Table-6
Result of assay of vermicompost for NPK contents

Treatment	As received in the laboratory				Oven-dry			
	% Moisture	% N	% P	% K	% N	% P	% K	Total % NPK
T_1 (RS-CaM)	49.68	0.93	0.28	0.41	1.97	0.58	0.87	3.42
T_2 (RS-ChM)	48.02	1.22	1.72	1.74	2.48	3.52	3.54	9.54
T_3 (RS-HM)	42.86	0.65	1.55	0.50	1.19	2.81	0.91	4.91
T_4 (GSL-CaM)	45.62	1.59	0.97	1.56	3.09	1.89	3.04	8.02
T_5 (GSL-ChM)	33.92	2.42	2.91	3.56	3.87	4.41	5.39	13.67
T_6 (GSL-HM)	40.41	1.40	1.99	1.16	2.38	3.38	1.96	7.72
T_7 (SD-CaM)	65.54	0.37	0.31	0.25	1.52	1.28	1.04	3.84
T_8 (SD-ChM)	54.95	1.03	1.99	2.18	2.63	5.10	5.59	13.32
T_9 (SD-HM)	50.78	0.37	1.90	0.50	0.86	4.41	1.15	6.42

Weight of Harvested Vermicompost: Data on the vermicompost weights are shown in table-7. The vermicompost yield was consistently significantly different among the treatment means. For the plant materials, the highest was in sawdust followed by rice straw and the lowest yield was in *G. sepium* leaves. The vermicompost dry matter contents were statistically the same for sawdust and cattle manure and lower for chicken manure. For animal manures, arranged from the highest are hog manure, cattle manure and chicken manure. This is true for the dry matter content of the vermicompost. Based on vermicompost yield and dry matter, the SD-HM substrate was the best followed by RS-CaM and RS-HM.This result is in accordance with the claim that the final weight and volume of vermicompost varies with original feedstock or substrate[4].

In general, materials with high C:N ratios give higher verminconpost yields because they create a more hospitable habitat for worms due to higher absorbency and bulking potential. This explains why high mortalities were observed when chicken manure and *G. sepium* leaves were used. The high N content of worm food is favorable to worm growth but high N content of bedding and the associated heating during decomposition could kill the worms[4].

Another important characteristic of bedding material is high bulking capacity and water-holding capacity. It was observed that the bulk of madre cacao is much reduced after precomposting and dried easily when placed in vermiculture boxes so that it required more frequent moistening. A little drying of the skin can kill worms because their bodies are of very high water content. The worms' ability to consume and convert the waste into vermicast varies according to the substrate and hence, the differences in vermicompost yield.

Conclusion

The substrates with sawdust and rice straw are favorable for increase in number and total weight gain of worms and less favorable with *G. sepium* leaves. Among the animal manures, hog manure is best for the reproduction and growth of worms. The individual weight is favored by higher nutritive value of substrate and by lower population density.In terms of percentage of N, the substrates with *G. sepium* leaves and chicken manure are superior to the other substrates. The use of hog manure combined with any of the plant materials result in highest concentration of P and K in the vermicompost. *G. sepium* leaves is also a good source of P and K. The SD-HM combination gave the highest vermicompost yield. In terms of worm and vermicompost production, sawdust and hog manure were better than the other materials. It is further concluded that sawdust can give higher weight gain and number of worms as well as the vermicompost yield compared with the rest of the substrates. However, *G. sepium* leaves and chicken manure are better materials in terms of individual worm weight and NPK contents of vermicompost. Different substrates give different result on selected vermicomposting parameters. Each substrate material has characteristics that are different from the characteristics of other materials and can influence differently the performance of worms. This means that the efficiency of vermicomposting is affected by the bedding materials and worm food source. Therefore, the selection and use of appropriate substrate materials could optimize vermicomposting efficiency.

There are still many researchable areas, broadly, in the field of earthworm biotechnology, and more specifically on the influence of bedding and food source or substrate as related to management and environmental variables. Although the findings can already be used as additional basis to establish the optimal conditions in terms of substrate to be used in vermicomposting in support to sustainable agriculture and waste management programs, further studies are recommended to explore the utilization of other bedding and food source materials and their combinations.

Table-7
Weight of dry matter, and NPK contained in the vermicompost recovered from 10-kg substrate

Treatment	Characteristic of Harvested Vermicompost						
	Total Weight	Moisture Content, %	Dry Matter Weight, kg	Weight of nutrient, grams			
				N	P	K	NPK
Factor 1: Plant material							
Rice straw	6600[b]	46.85	3421[a]	62.41[b]	73.36[b]	51.62[b]	187.39[c]
G. sepium leaves	3971[c]	39.98	2220[b]	70.66[a]	75.48[b]	75.64[a]	221.77[b]
Sawdust	7695[a]	57.09	3310[a]	51.33[c]	126.59[a]	80.04[a]	257.96[a]
Factor 2: Animal Manure							
Cattle	6556[b]	53.61	2996[b]	62.46[b]	32.62[c]	42.84[b]	137.92[c]
Chicken	4568[c]	45.63	2203[c]	68.76[a]	103.91[b]	114.95[a]	287.62[a]
Hog	7142[a]	44.68	3752[a]	53.18[c]	138.90[a]	49.51[b]	241.59[b]
Factor combination							
T_1 (RS-CaM)	8203[b]	49.68	4128[b]	81.32[a]	23.94[f]	35.91[f]	141.17[f]
T_2 (RS-ChM)	4443[f]	48.02	2050[de]	57.28[c]	81.30[d]	81.76[c]	220.35[d]
T_3 (RS-HM)	7152[c]	42.86	4087[b]	48.63[c]	114.84[c]	37.19[f]	200.66[d]
T_4 (GSL-CaM)	3979[g]	45.62	2280[d]	66.85[b]	40.89[e]	65.77[d]	173.52[e]
T_5 (GSL-ChM)	2860[h]	33.92	1736[e]	73.14[ab]	83.34[d]	101.86[b]	258.35[c]
T_6 (GSL-HM)	5075[e]	40.41	2643[c]	71.97[ab]	102.22[c]	59.27[de]	233.46[cd]
T_7 (SD-CaM)	7486[c]	65.54	2580[cd]	39.21[d]	33.02[e]	26.83[f]	99.06[g]
T_8 (SD-ChM)	6402[d]	54.95	2824[c]	75.85[a]	147.09[b]	161.22[a]	384.15[a]
T_9 (SD-HM)	9198[a]	50.78	4527[a]	38.93[d]	199.65[a]	52.06[e]	290.65[b]

Table-8
Results of ANOVA for vermicompost characteristics

Variable	Source of Variation	F-value	P-value	Difference
Weight of harvested vermicompost, grams	Plant Material (A)	175.47	0.000	Highly significant
	Animal Manure (B)	87.15	0.000	Highly significant
	Interaction (AxB)	12.13	0.000	Highly significant
Dry matter weight of vermicompost, grams	Plant Material (A)	80.66	0.000	Highly significant
	Animal Manure (B)	109.85	0.000	Highly significant
	Interaction (AxB)	28.83	0.000	Highly significant
Weight of nitrogen (N) in harvested vermicompost, grams	Plant Material (A)	38.20	0.000	Highly significant
	Animal Manure (B)	24.93	0.000	Highly significant
	Interaction (AxB)	38.24	0.000	Highly significant
Weight of phosphorus (P) in harvested vermicompost, grams	Plant Material (A)	166.53	0.000	Highly significant
	Animal Manure (B)	537.97	0.000	Highly significant
	Interaction (AxB)	47.51	0.000	Highly significant
Weight of potassium (K) in harvested vermicompost, grams	Plant Material (A)	59.86	0.000	Highly significant
	Animal Manure (B)	406.36	0.000	Highly significant
	Interaction (AxB)	65.97	0.000	Highly significant
Weight of NPK in harvested vermicompost, grams	Plant Material (A)	38.14	0.000	Highly significant
	Animal Manure (B)	180.12	0.000	Highly significant
	Interaction (AxB)	36.17	0.000	Highly significant

Acknowledgement

The author acknowledges the Department of Agriculture Region Field Office V-A, Philippines for funding the LSPU Vermicultureand Vermicomposting Project which included this study.

References

1. Rupani P.F., Mohd F. Md D. and Zelam D. Kanhere (2013). Sustainable management of different organic waste by vermicomposting technology, *Journal of Agricultural Technology*, 9(3) 529-539.

2. Shrivastava S. and Singh K. (2013), Vermicompost to Save Our Agricultural Land. *Research Journal of Agriculture and Forestry Sciences,* 1(4), 18-20.

3. Pathma J. and Sakthivel N. (2012). Microbial diversity of vermicompost bacteria that exhibit useful agricultural traits and waste management potential, *SpringerPlus*, 1(26) 2-20.

4. Munroe G. (2004), Manual of on-farm vermicomposting and vermiculture. http://www.organicagcentre.ca/ DOCs/ Vermiculture_FarmersManual_gm.pdf September 15, 2010-34.

5. Sinha R.K., Agarwal S., Chauhan K., Chandran V and Kiranbhai B. (2010), Vermiculture Technology: Reviving the Dreams of Sir Charles Darwin for Scientific Use of Earthworms in Sustainable Development Programs, *Technology and Investment*, 1, 155-172.

6. Latifah A.M., Mohd L.C., Mohd K.Y., Tengku H., Tengku I., Rosta H., Hafizan J. and Kamaruzaman J. (2009). Influences of Bedding Material in Vermicomposting Process, *International Journal of Biology*, 1(1) 81-91.

7. Sivakumaran S. (2014), Biodegradation of Saw in Plant Fertilizer, *Research Journal of Agriculture and Forestry Sciences,* 2(2), 13-19.

8. Guerrero R.D. (2004), Handbook of Vermicompost and Vermimeal Production and Utilization, *Aquatic Biosystems*, Laguna, Philippines, 1-42.

9. Sinha R.K. (2008), Vermiculture and Sustainable

Agriculture, *American-Eurasian J. Agric. and Environ. Sci.*, (5) 01-55.

10. Sivasankari B, Indumathi S. and Anandharaj M. (2013), A Study on life cycle of Earth worm Eudriluseugeniae. *International Journal of Research in Pharmacy and Life Sciences,* 1(2) 64-67.

11. Sinha R.K., Herat A.S., Asadi R. and Carretero E. (2002), Vermiculture Technology for Environmental Management: Study of Action of Earthworms *Eiseniafetida, Eudriluseuginiae* and *Perionyxexcavatus*on Biodegradation of Some Community Wastes in India and Australia, *The Environmentalist*, 22(2), 261-268.

12. Vasanthi K., Chairman K. and Ranjit Singh A.J.A. (2013), Influence of animal wastes on growth and Reproduction of the African earthworm species *Eudriluseugeniae* (Kinberg), *Poll Res.*, 32(2), 337-342.

13. Daniel T., Sivasankari B. and Malathy M. (2010), Microbial and nutrient enhancement of *Gliricidiasepium* and *Leucaenaleucocephala* leaf materials using Eiseniafetida, *in Vermitechnology II, N. Karmegam*, Ed., 4(1), 152–154.

14. Esaivani C, Esakiammal B., Vasanthi K., Nithya R and Chairman K. (2015), Vermiconversion of leaf wastes (*Ficusbenghalensis* and *Ficusracemosa*) by employing *Eudriluseugeniae*, *International Journal of Advanced Research*, 3(8), 798–806.

15. Rajendran P.E., Jayakumar S.K. and Gunasekaran P. (2008), Vermiculture and Vermicomposting Biotechnology for Organic Farming and Rural Economic Development, http://www.researchgate.net/publication/230641885.

16. Jesikha M. and Lekshemanasamy M. (2012), Reproductive Performance of *Eudriluseugeniae* (Kingberg) in *Pongamiapinnata* Leaf Medium, *International Interdisciplinary Research Journal*, Volume-II, Issue-VI,

17. Simons A.J. and Stewart J.L. (1998), *Gliricidiasepium*: A Multipurpose Forage Tree Legume in: Ross C. Gutteridge and H. Max Shelton Forage Tree Legumes in Tropical Agriculture, The Tropical Grassland Society of Australia Inc.

18. Myung Ho Um and Youn Lee (2001), Quality Control for Commercial Compost in Korea National Institute of Agricultural Science and Technology (NIAST), Rural Development Administration (RDA), Suwon 441-707, Korea, -10-01.

19. Dominguez J., Edwards C.A. and Ashby J. (2001), The biology and population dynamics of *Eudriluseugeniae* (Kinberg) (Oligochaeta) in cattle wastesolids, *Pedobiologia,* 45, 341–353.

20. Pattnaik S. and Reddy M.V. (2010), Nutrient Status of Vermicompost of Urban GreenWaste Processed by Three Earthworm Species- *Eiseniafetida*, *Eudriluseugeniae* and *Perionyx excavates*, *Applied and Environmental Soil Science*, 20, 101-14.

21. Gunadi B. and Edwards C.A. (2003), The effect of multiple applications of different organic wastes on the growth, fecundity and survival of *Eiseniafoetida* (Savigny) (Lumbricidae),*Pedobiologia,* 47(4), 321–330.

22. Suthar S. (2007), Vermicomposting potential of *Perionyxsansibaricus* (Perrier) in different waste materials, *Bioresource Technology,* 98, 1231–1237.

23. Vijaya T.M., Middha S.K.M., Usha T., Aruna H.K., Bharathi R., Saini Deepti and Govindaraj G. (2012), Morphological and Histological Studies on the Vermicomposting Indian Earthworm *Eudriluseugeniae. World Journal of Zoology*. 7(2), 165-170.

24. Vorsters A., Demey F. and Hardouin J. (1997), Influence of worm density on the growth of *Eudriluseuginiae. Tropicultura*, 15(2), 89-90.

25. Lange M.G., Baxter C. and Killian K. (2005), A comparison analysis of vermicomposting strategies in food substrates with an emphasis on nutrient values and reproduction, *The Big M,* 1, 1-14.

26. Sriramulu A. and Govindarajan G. (2005), Bioconversion of Municipal Solid Waste by the Earthworm *Eudriluseugeniae* (Kinberg), *International Research Journal of Biological Sciences*, 3(2), 70-73.

27. Ndegwa P.M. and Thompson S.A. (2000), Effects of C-to-N ratio on vermicomposting of biosolids, Elsevier Publishing, *Bioresource Technology*, 75, 7-12.

28. Sinha R.K., Hahn G., Singh P.K., Suhane R.K. and Anthony Reddy A. (2011), Organic Farming by Vermiculture: Producing Safe, Nutritive and Protective Foods by Earthworms (Charles Darwin's Friends of Farmers), *American Journal of Experimental Agriculture*,1(4), 363-399.

29. Mistry J., Mukhopadhyay A.P. and Baur G.N. (2015), Status of N P K in vermicompost prepared by two common weed and two medicinal plants, *Journal of Advanced Studies in Agricultural, Biological and Environmental Sciences*, 2(1), 25-38.

30. Kanchilakshmi M., Arockiam T., Chandrasekar and Sumathi G. (2015), Earthworm Processed Weeds on Plant Growth Attributes, *International Research Journal of Biological Sciences*, 4(7), 24-28.