VERMICOMPOSTING OF PALM OIL MILL EFFLUENT (POME) SLUDGE AND EFFECTS OF VERMICOMPOST ON OIL PALM SEEDLING GROWTH

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by

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LIST OF SYMBOLS

^{o}C	Celcius
min	minute
mm	millimeter
g	gram
kg	kilogram
ppm	parts per million
h	hour
m	meter
cm	centimeter
ml	milliliter
%	Percentage
L	Litre
mg	milligram
v	volume
meq	milliequivalents
dSm^{-1}	deciSiemens per meter
″	inch

LIST OF ABBREVIATIONS

N	nitrogen
P	phosphorus
K	potassium
Mg	magnesium
C	carbon
O	oxygen
H	hydrogen
C/N	carbon-nitrogen ratio
EC	electrical conductivity
Zn	zinc
Fe	iron
Mn	manganese
Pb	plumbum
VS	volatile solid
Ca	calcium
Cu	copper
CFU	colony forming unit
HCl	hydrochloric acid
ATR	Attenuated Total Reflectance
RBA	Rose Bengal Agar
PGR	plant growth regulators

PENGKOMPOSAN VERMI BAGI ENAPCEMAR EFLUEN KILANG MINYAK SAWIT DAN KESAN-KESAN VERMIKOMPOS KE ATAS PERTUMBUHAN ANAK KELAPA SAWIT

ABSTRAK

Kajian ini adalah berkaitan tentang pengkomposan vermi bagi enapcemar efluen kilang minyak sawit dan kesan-kesan vermikompos ke atas pertumbuhan anak kelapa sawit. Eksperimen terhadap pengkomposan vermi hanya bagi bahan rendah nisbah C/N, tanpa percampuran, adalah sangat terhad. Hanya terdapat beberapa sumber sahaja yang meniliti kajian ini. Objektif utama kajian ini adalah untuk mengkaji kebolehupayaan pengkomposan vermi bagi enapcemar efluen kilang minyak sawit di samping memviarasikan stok kepadatan cacing, iaitu *Eudrilus eugeniae*. Satu kajian untuk melihat bahan-bahan rendah nisbah C/N sebagai bahan pengkomposan vermi telah dibuat. Sisa enapcemar efluen kilang minyak sawit telah digunakan untuk menyediakan perkadaran pencampuran sisa enapcemar bersama stok kepadatan cacing yang berbeza, iaitu E0 (sisa enapcemar efluen kilang minyak sawit sahaja), E50 (sisa enapcemar efluen kilang minyak sawit + 0.24 kg-cacing/m^2) dan E100 (sisa enapcemar efluen kilang minyak sawit + 0.48 kg-cacing/m^2). Vermikompos dan kompos sisa efluen minyak kelapa sawit kemudiannya dianalisis secara kimia iaitu suhu, pH, jumlah nitrogen Kjedahl, nisbah C/N, konduktiviti elektrik, makro dan mikronutrien dan juga jumlah populasi mikrob. Eksperimen seterusnya terhadap aplikasi vermikompos ke atas pertumbuhan anak kelapa sawit juga dikaji. Kajian ini merumuskan bahawa vermikompos bersama 0.48 kg-cacing/m^2 stok kepadatan cacing memberikan peningkatan yang ketara dari segi kepekatan nitrogen dan kalium, begitu juga terdapat perbezaan yang ketara di dalam nisbah C/N, jika dibandingkan dengan kompos sisa enapcemar efluen kilang minyak sawit (kawalan).

Mikronutrien, iaitu kandungan kuprum juga memberikan peningkatan yang ketara di dalam vermikompos bersama 0.48 kg-cacing/m^2 stok kepadatan cacing, berbanding dengan kompos sisa enapcemar efluen kilang minyak sawit (kawalan). Jumlah populasi mikrob yang lebih tinggi juga telah dicatatkan bagi vermikompos bersama stok kepadatan cacing 0.48 kg-cacing/m^2. Di samping itu, kajian aplikasi terhadap anak pokok kelapa sawit sebagai penunjuk tumbuhan mencatatkan bahawa vermikompos meningkatkan kandungan nutrient di dalam tanah (fosforus dan kalium), selain memberikan peningkatan yang ketara terhadap jumlah bilangan pelepah sawit, jika dibandingkan dengan percampuran tanah bersama kompos biasa. Secara keseluruhannya, kajian ini membuktikan bahawa pengkomposan vermi bersama sisa enapcemar efluen kilang minyak sawit sebagai bahan rendah nisbah C/N boleh dilaksanakan.

VERMICOMPOSTING OF PALM OIL MILL EFFLUENT (POME) SLUDGE AND EFFECTS OF VERMICOMPOST ON OIL PALM SEEDLING GROWTH

ABSTRACT

The present study is about vermicomposting of palm oil mill effluent (POME) sludge as a low C/N ratio material and effects of vermicompost on oil palm seedling growth. Experiment on vermicomposting of low C/N ratio materials alone, without mixing, is very limited. There are limited literatures that have looked into this matter. The main objective of this work was to study the feasibility of vermicomposting of the sludge by varying worm stocking density, namely *Eudrilus eugeniae.* A review on materials with low C/N ratio as a substrate in vermicomposting with a proposal to vermicompost POME sludge was done. POME sludge was then used to prepare different proportions of worm stocking density with POME sludge mixtures, viz. E0 (POME sludge only), E50 (POME sludge + 0.24 kg-worms/m^2) and E100 (POME sludge + 0.48 kg-worms/m^2). Vermicompost and POME sludge compost were then chemically analyzed for various parameters namely, Total Kjeldahl Nitrogen (TKN), C/N ratio, Electrical Conductivity (EC), macro and micronutrients as well as microbial population. Further experiments on application of vermicompost towards total number of frond and height of oil palm seedlings have been studied. This study concluded that vermicompost with worm stocking density of 0.48 kg-worms/m^2 gives significantly higher results in terms of nitrogen and potassium concentration, as well as significantly different in C/N ratio, as compared to POME sludge compost (control). Vermicompost with stocking density of 0.48 kg-worms/m^2 also gives significantly higher copper content, as compared to POME sludge compost (control). A higher microbial population also was recorded in vermicompost with stocking density of 0.48 kg-worms/m^2. Meanwhile, the application of vermicompost (VC) towards oil palm seedlings as plants indicator revealed that there was a significant difference in terms of P and K content in VC mixed with soil as compared to chemical fertilizer (CF) mixed with soil (i.e. control). Total number of oil palm frond in VC mixed soil also was significantly higher as compared to normal compost (NC) mixed with soil. Overall, this study demonstrated that vermicomposting of POME sludge as low C/N ratio material is feasible.

CHAPTER 1

INTRODUCTION

1.1 General Background

During the past few decades, the oil palm (*Elaeis guineensis*) has become one of the most rapidly expanding equatorial crops in the world (Alengaram et al., 2013; Suriyan et al., 2013). As reported by Alengaram et al., (2013), the global extent of oil palm cultivation increased from 3.6 million ha in 1961 to 13.2 million ha in 2006. Malaysia is reported as one of the largest palm oil producer and exporter in the world. Regardless of its high economics return to the country, Amini et al., (2013) have reported that the industry also generates large amount of wastes (Alengaram et al., 2013) such as empty fruit bunch (EFB) (23%), mesocarp fibre (12%), shell (5%) and palm oil mill effluent (POME) (60%) for every tonne of fresh fruit bunches (FFB) processed in the mills.

For many years, the palm oil industry has contributed to the major revenue of Malaysia (Tan et al., 2013). However, its impacts on the environment are not negligible. Abate and Kronk, (2013) reported that the palm oil industry has had a destructive effect on the Malaysian ecology. According to Ohimain and Izah (2014), more than 70% (by weight) of the processed fresh fruit bunch (FFB) was left over as oil palm waste during sustainable management practice.

The most polluted organic residues generated from palm oil mills is POME. It composed of high organic content of oil and fatty acids (Yoshizaki et al., 2013).

Besides the damages brought by the upstream processes, the bad impacts are continued by the downstream processing of the fresh fruit bunch (FFB). In this respect, POME has been identified as the largest source of water pollution due to its high organic content and acidic nature (Tan et al., 2013). As quoted by Singh et al., (2013), POME which consisted of suspended solids and dissolved solids that left after POME treatment is known as palm oil mill effluent (POME) sludge. As POME production increases each year, the amount of POME sludge increases respectively.

Mohammad et al, (2012) reported that POME sludge has higher nutrient value than the slurry, pH around 8.4 as well as enriched with minerals such as calcium, potassium, sodium, magnesium, copper and iron. Unfortunately, POME sludge has bad odors as a result of its high content in total nitrogen, total phosphorus and potassium. It also plays a crucial impact on the environment, which makes it necessary to find a proper technology for mitigating these wastes (Singh et al., 2013). Therefore, it is considered as a source of surface and ground pollution.

Several studies on POME sludge have showed that POME sludge can be dried and used as a fertilizer as it contains high nutrient value (Abdurahman et al., 2013). According to Abdurahman et al., (2013), composting as well as vermicompost technology can be used in POME sludge management. Since the characteristics of partially treated POME was always varied and difficult to maintain in the open pond system which was influenced by weather condition and mill operation (Yoshizaki et al., 2013), therefore an approach has been taken to stabilize this waste by using vermicomposting.

Over the last few years, various researchers have examined the potential utilization of earthworm-processed wastes, commonly referred to as vermicompost, in the horticultural and agricultural industries (Erwan et al., 2013). The ability of some earthworms to consume a wide range of organic residues such as sewage sludge, animal wastes, crop residues, and industrial wastes of low and high C/N ratio materials by biological degradation process has been fully established (Kenyangi and Blok, 2013; Basheer and Agrawal., 2013; Yee Shak et al., 2014; Haiba et al., 2014). Various factors such as soil temperature, substrate moisture, types of waste substrate, as well as worm stocking density play a role in success of vermicomposting.

1.2 Problem Statement

The conversion of organic materials into a readily usable form can be indicated by the decline of its C/N ratio (Tripetchkul, 2012). Vermicomposting by mixing of high C/N ratio materials with low C/N ratio materials have been studied by many researchers (Cardoso-Vigeuros and Ramirez-Camperos, 2002; Kaushik and Garg, 2003; Nahrul et al., 2010; Baharuddin et al., 2010; Ludibeth et al., 2010; Tripetchkul et al., 2012), to obtain a starting substrate with suitable C/N ratio between 25-30 (Agriculture and Food, 1996; USDA, 2000).

However, a study on composting as well as vermicomposting of low C/N ratio materials alone, by varying worm stocking density, is very limited (Orozco et al., 1996). In relation to this, POME sludge was reported to have a C/N ratio around 8 (Yoshizaki et al., 2013). There are only few literature references that have looked into this matter and a study on vermicomposting with POME sludge unmixed as a low C/N ratio material has not been done yet.

The applications of vermicompost on plant growth and yield (especially on vegetative plants) also have been examined by many researchers (Edwards and Burrows 1988; Wilson and Carlile 1989; Mba, 1996; Buckerfield and Webster 1998; Edwards 1998; Subler et al., 1998; Erwan et al., 2013). However, the application of vermicompost of POME sludge on oil palm seedlings in recycling it back to the source plant has not yet been fully studied.

1.3 Objectives of Study

The general aim of this work is to study the feasibility of vermicomposting of POME sludge and the specific objectives of this study are:

I. To determine the physico-chemical changes of Palm Oil Mill Effluent (POME) Sludge as a material with low C/N ratio in vermicomposting by varying earthworm (*Eudrilus eugeniae*) stocking density;

II. To assess the effects of vermicompost on the height and number of frond of oil palm seedlings as compared to other fertilizers under nursery conditions.

1.4 Research Scope and Limitation

The main purpose of this work is to study the decomposition or degradation of POME sludge as a low C/N ratio material via vermicomposting. The resultant vermicompost is tested by using oil palm seedlings as plants indicator. This study is not about producing vermicompost as a complete fertilizer from the agricultural perspective as well as not on the vermiculture of earthworms.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Oil Palm Industry

2.1.1 Introduction

Originally from West Africa, the oil palm, *Elaeis guineensis*, has over the last century been an increasingly important driver for the economies of producing countries in South-East Asia, Papua New Guinea, Central and West Africa and to a lesser extent in tropical Latin America. According to Basri et al., (2010), the highly efficient producer of vegetable oil is an oil palm, as compared to other oil-bearing crops. Oil palm plantation only needs 0.26 ha of land to produce 1 tonne of oil, compared with 2.2, 2.0 and 1.5 ha for soya bean, sunflower and rape, respectively. Through research and development (R&D), the oil palm yield is expected to increase further to produce 10 times the energy it consumes, thereby out-performing oil seeds like soya bean and rape by ratios of 2.5 and 3, respectively (Basri et al., 2010).

Palm oil was first introduced in Malaysia in 1875 (Ibrahim et al., 1999). There was an early interest in the oil palm as an ornamental plant. Since 1917, the oil palm sector began its development into what is witnessed today as a multi-billion Ringgit industry, and currently palm oil has become world's largest source of edible oil, which amounts to 25% of the world total fat and edible oil production (Ibrahim et al., 1999). Malaysia is gifted with the ideal climate conditions for oil palm growing. Therefore, it is in Malaysia that crop's full potential can be realized and exploited (Kiew Ling et al., 2011).

2.1.2 Oil Palm Biomass Production

According to Plantation Industries and Commodities, Deputy Minister Datuk Hamzah Zainudin, Malaysia produced an estimated 80 million tonnes dry weight of oil palm biomass in 2011, reflecting the importance and significant potential of biomass (The Oil Palm, 2012). This biomass includes empty fruit bunches, mesocarp fibers, oil palm shells, oil palm fronds and oil palm trunks. In addition, about 54 million tonnes of palm oil mill effluent, which is mainly water but also contains a substantial amount of biomass solids, was produced (The Oil Palm, 2012).

According to Basiron and Simeh (2005), oil palm is a prolific producer of biomass as raw materials for value-added industries. It acts as a multi purposed plantation as well. For example, fresh fruit bunch contains only 21% palm oil, while the rest 6–7% palm kernel, 14–15% fiber, 6–7% shell and 23% empty fruit bunch (EFB) are left as biomass, as reported by Umikalsom et al., (1997).

2.1.3 Oil Palm Processing

In general, the palm oil milling process can be categorized into a dry and a wet (standard) process. The wet process of palm oil milling is the most common and typical way of extracting palm oil, especially in Malaysia. It is estimated that for each ton of crude palm oil that is produced, 5–7.5 t of water are required, and more than 50% of this water ends up as palm oil mill effluent (POME) (Ahmad et al., 2003). Raw POME is a colloidal suspension containing 95–96% water, 0.6–0.7% oil and 4–5% total solids (Ahmad et al., 2003). Included in the total solids are 2–4% suspended solids, which are mainly constituted of debris from palm fruit mesocarp generated from three main sources, i.e. sterilizer condensate, separator sludge and hydrocyclone wastewater (Zinatizadeh et al, 2007; Singh et al., 2010; Ma, 2000). If the untreated effluent is discharged into watercourses, it is certain to cause considerable environmental problems (Rupani et al., 2010) due to its high biochemical oxygen demand (25,000 mg/L), chemical oxygen demand (53,630 mg/L), oil and grease (8370 mg/L), total solids (43,635 mg/L) and suspended solids (19,020 mg/L). The palm oil mill industry in Malaysia has thus been identified as the one discharging the largest pollution load into the rivers throughout the country.

2.1.4 Environmental Concerns

The volume of oil palm biomass produced annually is much larger than the amount used in any other conversion processes, as reported by Kelly-Yong et al., (2007). Yusoff (2006) reported that surplus will occur, ultimately causing the biomass to be discarded. Empty fruit bunches, fiber and shells that form a large quantity of biomass are normally dumped in open areas or disposed in open burning, which later on generating pollutant gases (Yusoff, 2006).

Nowadays, the 5R policy (reduction, replacement, reuse, recovery and recycling) is widely promoted (Kiew Ling et al., 2011). The 5R policy applies a concept of cleaner production and environmentally sound biotechnologies in wastewater management. Besides, a “zero waste” concept (Ibrahim et al., 1999; Motavalli, 2001; Cheah, 2007) is now being directed by the MPOB as an environmental goal for this agro-industrial sector and aims to optimize the utilization of oil biomass as the recycled input into the plantations or for the production of commercial products as well as the generation of energy.

2.2 Treatments of Palm Oil Mill Effluent (POME)

Ponding system is the most conventional method for treating POME (Singh et al., 2010) but other processes such as aerobic and anaerobic digestions, physicochemical treatments and membrane filtration may also provide the palm oil industries with a possible insight into the improvement of current POME treatment process. However, the treatment that is based mainly on biological treatments of anaerobic and aerobic systems is quite inefficient to treat POME, which unfortunately leads to environmental pollution issues (Ahmad et al., 2005).

Anaerobic treatment, evaporation method as well as membrane treatment system are the alternative methods for treatment being used currently (Poh and Chong, 2009). Meanwhile, Metcalf and Eddy (2003) also reported that untreated wastewater with BOD/COD ratio of 0.5 and greater can be treated easily by biological means. With reference to the published values of BOD and COD in Data for Engineers: POME (2004), aerobic and anaerobic treatment is suitable for POME treatment since the BOD/COD ratio is of 0.5. Poh and Chong (2009) also reported that the anaerobic treatment can be regarded to be more suitable for POME treatment in comparison of those two treatment methods, due to its lower energy consumption while producing methane as a value-added product in the process.

2.3 Characteristics of POME

Nitrogen is originally present in POME in the form of organic (protein) nitrogen and as time progresses the organic nitrogen is gradually converted to ammoniacal nitrogen with a molecular weight of 17–35 kg/ kmol (Ta et al., 2009). The nutrient balance in terms of the average ratio of BOD:N:P for raw POME is 100:4:0.3.

Muhrizal et al., (2006) reported that POME is characterized by a low C:N ratio ($C:N_{POME}$ = 6.54) as compared to sawdust ($C:N_{sawdust}$ = 185.74), purun ($C:N_{purun}$ = 88.32) and peat ($C:N_{peat}$ = 50.31). Only N, P, K, Mg and Ca are consistently present in relatively large amounts in the POME (Muhrizal et al., 2006).

Table 2.1 below shows the application of POME as fertilizer for palm oil plantations as reported by Onyia et al., 2001 in her study of increasing the fertilizer value of palm oil mill sludge. Muhrizal et al., (2006) also reported that POME has a high content of Al as compared to chicken manure and composted sawdust. It would thus seem that the probable usefulness of POME as fertilizer or animal feed substitute, in terms of providing sufficient mineral requirements, depends mainly on the soluble fraction of POME (Muhrizal et al., 2006). Toxic metals, such as Pb, can also be found in POME but their concentrations are usually below sub-lethal levels (N= 17.5 μg/g) (Onyia et al., 2001). POME is thus not toxic for plants and animals. Pb is found in POME due to contamination from plastic and metal pipes, tanks and containers where Pb is widely employed in paints and glazing materials (Onyia et al., 2001).

Table 2.1: The application of POME (m^3/acre/year) as fertilizer for palm oil plantations (Onyia et al., 2001)

Crops	N	P	K	Mg
Young palms	25-70	27.5-32	5.1-10	1.2-10
Adults palms	90-128	52.5	10-18.5	15
Old palms	162	52	18	20

2.4 Characteristics of POME Sludge

POME contains significant amounts of solids, both suspended solids and total dissolved solids that are commonly known as palm oil mill sludge (POME sludge)

(Rupani et al., 2010). The solid wastes produced by extraction process were from leaves, trunk, decanter cake, empty fruit bunches, seed shells and fibre from the mesocarp (Rupani et al., 2010).

As large quantity of POME is produced each year, the amount of POME sludge also increases (Rupani et al., 2010). As reported by Zakaria et al., (1994), POME sludge contains higher nutrients than the slurry in terms of pH (i.e. 8.4, high amount of moisture content and enriched with nutrients). Table 2.3 shows physico-chemical analysis of raw POME sludge as compared to empty fruit bunch. From the table, NPK ratio of POME sludge recorded was 3.6:0.9:2.1 (mg/L).

Table 2.2: Physico-chemical analysis of raw POME sludge as compared to empty fruit bunch (Baharuddin et al., 2009). All units in mg/L except moisture content and pH.

Parameters	POME sludge (average)	Empty fruit bunch
Moisture content (%)	85	60
pH	8.4	6.7 ± 0.2
Organic matter	60	-
Total organic carbon (TOC)	33.0	-
Total nitrogen (TN)	3.6	58.9 %
Phosphorus (P_2O_5)	0.9	0.6 ± 0.1 %
Potassium (K_2O)	2.1	2.4 ± 0.4 %

2.4.1 Management of POME Sludge

According to Chooi (1984), since POME sludge contains high nutritional value, it can be dried and used as a fertilizer. Normally, drying is mostly done in open ponds. The oil palm mills generate many by-products and wastes besides the liquid wastes that may have a significant impact on environment if they are not properly handled with. As per Rupani et al., (2010), POME sludge plays crucial impact on the environment caused from POME treatment. Therefore, it is necessary to find a proper technology for mitigating these wastes. Thus, composting as well as vermicomposting technology can be used in POME sludge management (Rupani et al., 2010).

2.5 Vermicomposting

The concept of vermicomposting started from the knowledge that certain species of earthworms consume a wide range of organic residues very rapidly, converting them into vermicompost, a humus-like, soil building substance in short time. Therefore, the effective use of the earthworms in organic waste management requires a detailed understanding of the effect of the physico-chemical properties of the substrate (Singh et al., 2005). Meanwhile, according to Hayawin et al. (2013), vermicomposting is a decomposition process involving interactions between earthworms and microorganisms and it is an economical, viable and sustainable option for oil palm wastes management.

The same idea was also cited by Parveen et al. (2010), stating that vermicomposting is described as composting or natural conversion of biodegradable waste into high quality fertilizer with the help of earthworms. Vermicomposting is the process in which earthworms are used to convert organic materials into humus-like material known as vermicompost or earthworm compost. Through vermicomposting process physical, chemical and biological reactions take place, resulting changes in the organic matter. The resultant product (vermicast) is much more fragmented, porous and microbially active (Am-Euras, 2009).

Vermicomposting is also explained as the application of earthworm in producing vermifertilizer, which helps in the maintenance of better environment and results in sustainable agriculture (Sudhakar et al., 2002). In contrast to traditional microbial waste treatment, vermicomposting process results in bioconversion of the organic wastes into two useful products: the earthworm biomass and the vermicompost. Earthworm biomass can further be processed into proteins as a source of animal feeds (Am-Euras, 2009).

In addition, as cited by Nagavallemma et al. (2004), vermicompost improves growth, quality and yield of different field crops, flower and fruit crops. Vermicomposting contributes to recycling of nitrogen and augments soil physico-chemical as well as biological properties.

The optimum temperature for non-burrowing earthworms in vermicomposting is about 25-30°C (Nagavallemma et al., 2004) and moisture level in pile ranges from 70±5% (Giraddi, 2008). It is a very simple process and easy to practice as well as cost-effective pollution abatement technology. Meanwhile, Nagavallemma et al., (2004) concluded that vermicomposting is a simple biotechnology process of composting, in which certain species of earthworms are used to enhance the process of waste conversion and produce a better end product.

Vermicomposting differs from composting in several ways (Nagavallemma et al., 2004). It is a mesophilic process, utilizing microorganisms and earthworms that are active at 28-34°C (Sivasankari et al., 2013). The process is faster than composting, because the material passes through the earthworm producing castings (worm manure) which are rich in microbial activity and plant growth regulators, and fortified with pest repellence attributes as well. In short, through a type of biological alchemy, vermicomposting is capable of transforming garbage into 'gold' (Vermi Co., 2001; Tara Crescent, 2003).

2.5.1 Types of Earthworm Species Used In Vermicomposting

Different requirements for optimal development, growth and reproduction of the earthworms are needed for different earthworm species with different organic wastes (Garg and Kaushik, 2005). There are more than 4400 named species of earthworms on this planet, and they have been broken down into categories such as endogeic, anecic and epigiec by researchers, largely descriptive of their habits in the soil. It is generally known that epigeic species have a greater potential as waste decomposers than anecics and endogeics. This is due to predominantly humus consuming surface dwelling nature of the epigeics. The most commonly used epigeic species are *Eudrilus eugeniae* Kinberg, *Eisenia foetida* Savigny, and *Perionyx excavates* Perrier (Gajalakshmi and Abbasi, 2004; Edwards, 1998).

All of the above three species are prolific feeders and can feed upon a wide variety of degradable organic wastes. They exhibit high growth rate. In the study conducted by Gajalakshmi et al. (2001), four species of detritivorous (humus-former) earthworms were tested for their ability to vermicompost paper waste blended with cow dung in 6:1 (w/w) ratio. The species used were *E. eugeniae, P. excavatus, L.mauritii* and *Drawida willsi* Michealsen. Results showed that the feasibility of vermicomposting as a viable process for the gainful utilization of paper waste in an environmental clean manner. Gajalakshmi et al. (2001) also reported that all the four species are suitable for the purpose, with *L. mauritii* and *E. eugeniae* a shade more efficient than the other two species.

2.5.1 (a) *Eudrilus eugeniae* (Kinberg, 1867)

E. eugeniae belongs to the Eudrilidae; it is a native African species that lives in both soils and organic wastes but has been bred extensively in the United States, Canada, and elsewhere for the fish-bait market, where it is commonly called the African night crawler (Dominguez et al., 2001). It is a large, robust earthworm that grows extremely rapidly, and it is relatively prolific when cultured. Under optimum conditions, it could be considered an ideal species for animal feed protein production. Its main disadvantages are a relatively narrow temperature tolerance and some sensitivity to handling (Dominguez et al., 2001).

As mentioned earlier, *E. eugeniae* is classified as epigeic or humus feeder earthworm. It typically inhabits humus-laden upper layers of garden earth and manure-pits. This species has higher frequency of reproduction and faster rate of growth to adulthood than most other species. Thus, these factors make it efficient utilizers of humus, manure and other forms of organic carbon. Further, as this species do not burrow into the soil, the vermireactors based on them need not contain deep bed of soil.

This has the potential of contributing towards saving on reactor volume, in turn contributing to favorable economics. For all these reasons, *E. eugeniae* has been extensively used in vermicomposting throughout the world (Tin et al., 1995;

Gajalakshmi et al., 2001a, 2001b) and has proved to be efficient converters of organic feed, especially manure, into vermicast.

2.5.1 (b) *Eisenia foetida* (Savigny, 1826) and *Eisenia Andrei* (Bouche, 1972)

The closely related *E. foetida* and *E. andrei* species are the ones most commonly used for the management of organic wastes by vermicomposting (Dominguez et al., 2001). There are several reasons why these two species are preferred: they are peregrine and ubiquitous with a worldwide distribution, and many organic wastes become naturally colonized by them; they have good temperature tolerance and can live in organic wastes with a range of moisture contents. According to Dominguez et al., (2001), *E. foetida* and *E. andrei* are resilient earthworms and can be handled readily; in mixed cultures with other species, they usually become dominant, so that even when systems begin with other species, they often end up with dominant *Eisenia* spp.

The biology and ecology of vermicomposting of *E. foetida* and *E. andrei* with animal manures or sewage sludge have been investigated by several authors (Dominguez et al., 2000). Under optimal conditions, their life cycles, from freshly deposited cocoon through sexually mature clitellate earthworm and the deposition of the next generation of cocoons, range from 45 to 51 days. The time for hatchlings to reach sexual maturity ranges from 21 to 30 days. Copulation in these species, which takes place in the organic matter, has been prescribed by various authors since 1845 and has been observed more often than for any other megadrile species (Dominguez et al., 2001).

2.6 Effect of Stocking Rate of *Eudrilus eugeniae* (Kinberg, 1867) on Vermicompost Production

The information on stocking rates of earthworms is necessary for effective recycling of organic residues in vermicomposting. A study by Giraddi (2008) was undertaken to determine the optimum introduction density of earthworms for recycling of crop wastes. African night crawler, *E. eugeniae* was used at four densities of 100, 150, 200 and 250 worms per 1 x 1 x 0.5 m bed. Soybean crop residue and little millet straw with C/N ratios of 20:1 and 46:1, respectively were used as food substrates, with total quantity amounting to 30 kg/replicate. The obtained results revealed that the influence of earthworm density on vermicompost production followed similar trend with significantly highest quantity of vermicompost harvested at 250 worm density (16.25 kg), followed by 200 worms (14.75 kg), 150 worms (12.75 kg) and 100 worms (11.40 kg).

However, a higher productivity rate was observed at 100 worms when conversion rates were assessed per worm basis, which decreased by successive increase in earthworm density. Giraddi (2008) concluded that it is obvious that beyond a threshold density limit, earthworms compete with each other for space and food and such intraspecific competition is more pronounced under conditions of crowding. Thus, at higher stocking rates, the increase in population growth rates was not as per theoretical rates of multiplication.

Giraddi (2008) study was supported by a study conducted by Kale and Bano (1988) and Reinecke and Viljoen (1991), which observed that the growth rate and reproduction are controlled by population density. Earthworms remain small in numbers and size and produce less number of cocoons when they are crowded. Similar observations by Hegde et al., (1997) on effect of crowding on population growth rate have been reported in *E. eugeniae* worms.

2.7 Importance of Vermicompost

2.7.1 The plant growth promoter and soil conditioner

The role of earthworm in the breakdown of organic debris on the soil surface and in the soil turnover process was first highlighted by Darwin (Sudhakar et al., 2002). Since 1978, there has been increasing interest in possible methods of processing organic wastes using earthworm to produce valuable soil additives. Earthworm is specialized to live in decaying organic wastes and can degrade it into fine particulate materials, which are rich in available nutrients with considerable potential as soil additives to revive the productivity status of soil (Dominguez et al., 2001; Sudhakar et al., 2002).

Earthworm can consume practically all kinds of organic wastes, consume two to five times its body weight and after using 5-10 per cent of the feed stock for its growth, excrete mucus coated undigested matter as worm casts. It is estimated that 1000 tonnes of moist organic matter can be converted by earthworms into 300 tonnes of compost (Am-Euras, 2009).

Earthworms vermicompost is proving to be highly nutritive 'organic fertilizer' and more powerful 'growth promoter' over the conventional composts and a 'protective' farm input (increasing the physical, chemical and biological properties of soil, restoring and improving its natural fertility) against the 'destructive' chemical fertilizers which has destroyed the soil properties and decreased its natural fertility over the years (Sudhakar et al., 2002; Dominguez et al., 2000). Vermicompost is rich in NPK (nitrogen 2-3%, potassium 1.85-2.25% and phosphorus 1.55-2.25%), micronutrients, and beneficial soil microbes and also contain plant growth hormones and enzymes (Dominguez et al., 2000). It is scientifically proving as 'miracle' growth promoter and also plant protector from pests and diseases.

Vermicompost retains nutrients for long time and while the conventional compost fails to deliver the required amount of macro and micronutrients including the vital NPK to plants in shorter time (Sudhakar et al., 2002). Significantly, vermicompost works as a soil conditioner and its continued application over the years lead to total improvement in the quality of soil and farmland, even on degraded and sodic soils. Experiments conducted in India at Shivri farm of 'U.P. Bhumi Sudhar Nigam' (U.P. Land Development Corporation) to reclaim sodic soils gave very good results (Sudhakar et al., 2002).

2.7.2 Improved soil physical, chemical and biological properties

Studies in vermicompost indicate that it increases macrospore space ranging from 50 to 500 μm, resulting in improved air-water relationship in the soil which favorably affects plant growth (Marinari et al., 2000). The application of organic matter including vermicompost favorably affects soil pH, microbial population and soil enzyme activities (Maheswarappa et al., 1999). It also reduces the proportion of water-soluble chemical species, which cause possible environmental contamination (Nagavallemma et al., 2004).

Organic materials which are degraded through the activities of successive groups of microorganisms is an aerobic process of composting, as cited by Rebollido et al., (2008) in Gajdos (1992). Eventhough composting is a microbiological process, but little known that microorganisms is actually involved as well as their activities, during specific phases of the composting process. As reported by Tiquia and Michel (2002), the diversity and structure of microbial communities of compost through their constituent populations has been of considerable interest to compost researchers in order to address basic ecological questions such as how similar are microbial communities in mature compost that were made from different feedstock and using different composting methods.

Meanwhile, the composition of the microbial communities during composting is determined by many factors such as temperature, water content, C/N, etc. In addition, under aerobic conditions, temperature is the major selective factor for populations and determines the rate of metabolic activities (Rebollido et al., 2008). Several authors have noted that the earthworms play a major role in affecting populations of soil organisms, especially in causing changes in the soil microbial community (Coleman, 1985; Parmelee ,1998). According to Subler et al., (1998), vermicompost is much richer in microbial diversity, populations and activities in conventional thermophilic composts.

Ranganathan and Parthasarathi (2000) reported that earthworms inevitably consume the soil microbes during the ingestion of litter and soil. They also have been estimated that earthworms necessarily have to feed on microbes, particularly fungi for their protein/nitrogen requirement.

2.8 Factors determining the nutritional quality of vermicompost

The nutritional quality of vermicompost is determined primarily by the type of the substrate (raw materials) and species of earthworms used for composting, along with microbial inoculants, liming, aeration, humidity, pH and temperature. Cattle dung has been found to yield most nutritive vermicompost when composted by *Eisenia feotida*. Pramanik (2007) found that application of lime @ 5 gm/kg of substrate and 'microbial inoculation' by suitable 'cellulolytic', 'lignolytic' and 'N-fixing' strains of microbes not only enhance the rate of vermicomposting but also results into nutritionally better vermicompost with greater enzymatic (phosphatase & urease) activities.

Kaushik and Garg (2004) found that inoculation with N-fixing bacteria significantly increased the nitrogen (N) content of the vermicompost. Liming generally enhance earthworm activities as well as microbial population. Earthworms after ingesting microbes into its gut proliferate the population of microbes to several times in its excreta (vermicast). It is therefore advantageous to use beneficial microbial inoculants whose population is rapidly increased for rapid composting and also better compost quality.

Pramanik (2007) studied the vermicomposting of four (4) substrates viz. cow dung, grass, aquatic weeds and municipal solid wastes (MSW) to know the 'nutritional status and enzymatic activities' of the resulting vermicomposts in terms of increase in total nitrogen (N), total phosphorus (P) and potassium (K), humic acid contents and phosphatase activity.

In Total Nitrogen result, Pramanik (2007) found that cow dung recorded maximum increase in nitrogen (N) content (275%) followed by MSW (178%), grass (153%) and aquatic weed (146%) in their resulting vermicompost over the initial values in their raw materials. Application of lime without microbial inoculation, however, increased N content in the vermicompost from 3% to 12% over non-limed treatment, irrespective of substrates used.

Meanwhile, for Total Phosphorus and Potassium, similarly, the vermicompost prepared from cow dung had the highest total phosphorus (12.70 mg/g) and total potassium (11.44 mg/g) over their initial substrate followed by those obtained from aquatic weeds, grasses and MSW (Pramanik, 2007).

Furthermore, phosphatase activity for vermicompost obtained from cow dung showed the highest acid phosphatase (200.45 μg p-nitrophenol/g/h) activities followed by vermicompost from grasses (179.24 μg p-nitrophenol/g/h), aquatic weeds (174.27 μg p-nitrophenol/g/h) and MSW (64.38 μg p-nitrophenol/g/h) (Pramanik, 2007). The alkaline phosphatase activity was highest in vermicompost obtained from aquatic weeds (679.88 μg p-nitrophenol/g/h) followed by cow dung (658.03 μg p-nitrophenol/g/h), grasses (583.28 μg p-nitrophenol/g/h) and MSW (267.54 μg p- nitrophenol/g/h). This was also indicated by Vinotha, (2000).

2.9 Carbon mineralization during vermicomposting

As the worm processes organic matter (OM), it modifies the sources of C, N and by means of the C/N ratio, which reports the quality of the obtained product. Organic C decreases by the end of vermicomposting, from different factors, namely: i) the worm consumption of organic C; ii) the transformation into carbon dioxide (CO_2) by the respiratory activity; iii) the formation of humic fraction that makes room for mature vermicompost (Singh et al., 2005; Garg et al., 2006; Suthar, 2009).

Dominguez (2004) also reported that earthworms can assimilate carbon best from the more recently deposited organic matter fractions, consisting mainly of easily degradable substances. The degradation process resulted in carbon losses by mineralization, which produced a decrease in the amounts of total organic carbon and in the carbon contributions to the organic matter.

2.10 Nitrogen transformations during vermicomposting

Del Aguila Juárez et al., (2011) reported that N increases by the end of the vermicomposting process and responds to i) the elaboration of products (metabolites) that contain N by the worm; ii) the excrete of mucus that is a fluid rich in N eliminated by the worm; iii) the substratum enzymes, NH_4^+, dead tissue rich in N; and iv) the mineralization process during vermicomposting (Chaudhuri et al., 2000; Aira et al., 2006; Muthukumaravel et al., 2008). C/N ratio expresses the quantity of C and N that has to be included to elaborate a vermicompost and it decreases by the end of the process (Yadav and Garg, 2009).

Meanwhile, a study by Dominguez (2004) on vermicomposting of pig slurry reported that earthworms had a great impact on the nitrogen transformations in the pig manure by enhancing nitrogen mineralization, so that most mineral nitrogen was retained as nitrates. He also reported the decrease in the net total nitrogen and the different nitrogen fractions during vermicomposting and important reductions in organic nitrogen content and recorded its high nitrification rate.

Stabilization of organic wastes by vermicomposting is highly desirable as it eliminates odor, increases nutrient contents, and prevents the organic wastes from becoming phytotoxic when incorporated into the soil (Kuo et al., 2004; Suthar, 2008). The ability of some earthworm species to consume a wide range of organic residues such as sewage sludge, animal wastes, crop residues, and industrial refuse has been well-established (Mitchell et al., 1980; Edwards et al., 1985; Chan & Griffiths, 1988; Hartenstein and Bisesi, 1989). The most commonly used of earthworm in breakdown or organic wastes are *Eisenia foetida* and *Eisenia andrei* (Atiyeh at al., 2000).

Figure 2.1 shows a more comprehensive look of nitrogen cycle in agricultural industry. Most agriculture factories produced nitrogen fertilizer. However, in palm oil mill, it produces nitrogen-containing sludge. When discharged on the ground (open ponding system), the nitrate-bacteria converts ammonium to plant-usable nitrate (Scott and Daryl, 1993).

In vermicomposting, ammonium-bacteria in vermicompost convert organic nitrogen in POME sludge into plant-usable ammonium. Later on, the nitrate-bacteria in POME sludge will convert the ammonium to plant-usable nitrate. The application of vermicompost on plants caused the plants take up the nitrates and ammonium which then gives some good effects on their growth and productivity (Scott and Daryl, 1993).

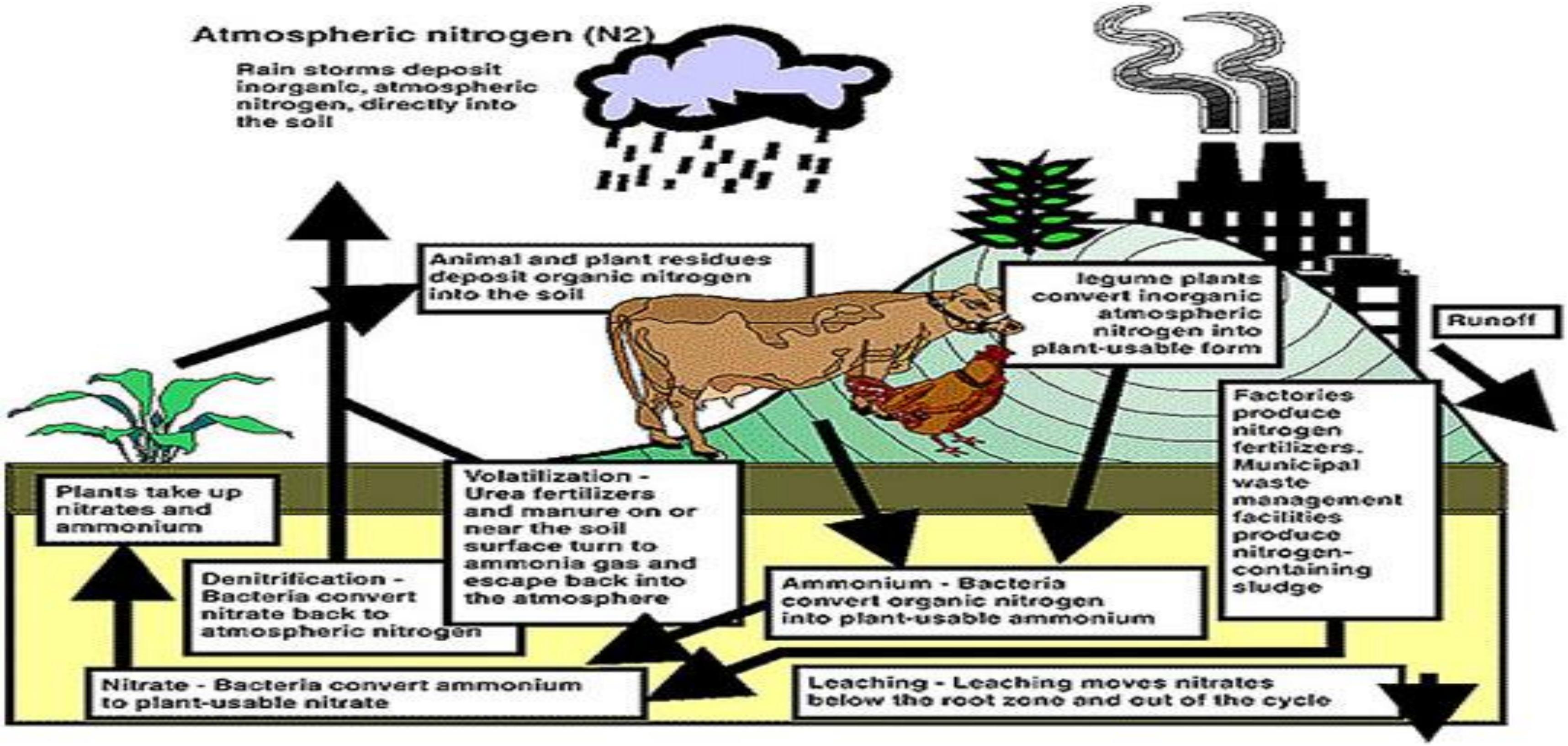

Figure 2.1: A more comprehensive look at the nitrogen cycle. (Source from: Scott and Daryl, 1993).