CHAPTER 1 INTRODUCTION

1.1 Waste Composition in Malaysia

Waste is an inevitable by-product that arises from various anthropogenic activities and it is also considered as one of the major sources of environmental degradation since it causes air, land and water pollution and contributes to global warming (Peter, 2010). Different kinds of industries, change of lifestyle and population growth are assumed to be within the main factors that increase the rate of waste generation globally and locally. Hence, proper waste management options are vitally important based on the types of wastes and cost-effective factors in order to further reduce environmental degradation and ecosystem destruction.

Malaysia, like most developing countries, is facing an increase in the generation of waste and accompanying problems associated with waste disposal (Lina, 2004). The Malaysian population was 28.96 million in 2010, experiencing 1.6% growth as compared to 28.31 million in 2009 (http://www.malaxi.com, 2010). As such, waste generation has increased by 3% annually which has alarmed the waste managers (Fauziah and Agamuthu, 2009). The national average of 1.3 kg/capita is expected to be increasing linearly, reaching 2.23 kg/capita by 2024 (Mohamad *et al*., 2009). Approximately 30,000 tons of municipal solid wastes are generated daily, covering 83% of the country's waste generation, including agrowastes. About 95% of the total wastes are sent to landfills for disposal (Fauziah and Agamuthu, 2009). Clearly, the way to limit the impact on the environment is by reducing the amount of waste that is generated, or the waste must be recycled, composted or reused.

When these options are unsuitable, then the waste needs to be incinerated or landfilled (Antonio and Domenico**,** 2008).

1.2 Overview on Agro-Industrial Waste

Generation and composition of industrial wastes vary depending on the type of industry. Different countries apply various categorisations for industrial waste which contribute adversely to water, soil and air quality (Samuelson, 2009). Some industrial wastes are neither hazardous nor toxic, but organic waste such as coconut shells, produced by agro-based industry, is not hazardous in nature and thus have potential for other uses (Samuelson, 2009).

The agricultural industry plays a significant role in the overall economic growth in the world (Kamal *et al*., 2009). Globally, 998 million tonnes of agricultural waste is produced per year and in Malaysia, 1.2 million tonnes of agricultural waste is disposed of into landfills annually (Agamuthu, 2009). It is estimated that 15% of the total waste generated in Asia is agrowaste, with agricultural waste generation in Malaysia at approximately 0.122 (kg/cap/day) in 2009 which is projected to reach 0.210(kg/cap/day) by 2025 (Agamuthu, 2009). Based on the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories in 2006, agro-based industry produces a significant amount of post-processing waste and residue in Malaysia, such as palm oil and industries concerning the fabrication of rubber-wood products. Even though agro-based industry generates various types of waste, these wastes are mostly composed of organic matter which has high potential to be converted into value added products.

1.2.1 Coconut Industry in Malaysia

Coconut is a well-known fruit in Malaysia and the degree of diversification of coconut utilization for food products is a remarkable achievement. According to the Food and Agricultural Organization of the United Nations, Malaysia was placed ninth, before Tanzania, in the top ten coconut producers in the world in 2009 by producing 555,120 tonnes per year. Coconut (*Cocos nucifera)* is an important member of the Arecaceae family (palm family). It can grow up to 30 m tall, with 4–6 m long pinnate leaves and 60–90 cm pinnate. The term coconut refers to the entire coconut palm, the seed, or the fruit, which is not a botanical nut (jhenz, 2008).

The coconut industry in Malaysia is considered as one of the new emerging industrial crops that could bring a significant impact to the country's economy. In 2009, coconut-based industry received about RM 29 million as an incentive to boast its growing impact in the agricultural sector (Abd Razak *et al*., 2010).

Based on the National Coconut Conference in 2009, coconut is grown in 93 countries covering 12 million hectares. In Malaysia, it is presumed that coconut is the fourth most important crop in terms of acreage, after oil palm, rubber and paddy. Furthermore, It has significant socio-economic implications as it is estimated to provide a source of revenue for 80,000 households and supports a vibrant small and medium sized coconut-based industrial sector with a positive trade balance of about RM81.2 million in 2007 (http://www.anjungnet.mardi.gov.my, 2009). Coconut waste is a copious agricultural waste and it also composes part of kitchen waste. The waste is generated from different parts of the coconut head, namely the husk, kernel and meat (inner part). In the past, such types of agro-waste have been utilised as animal feed or organic fertilizer or are otherwise allowed to decay naturally in fields, discarded or burnt, whereas current practices are on-farm burning, burial, stockpiling and landfilling (Agamuthu, 2009). Despite its reuse as animal feed/ supplement, it also can be utilised as organic fertilizer via bioconversion.

1.2.2 Kapar Coconut Industries (KC) Sdn. Bhd.

Kapar Coconut Industries (KC) Sdn. Bhd., is one of the largest coconut-based industries in Malaysia. It is part of SB Food Industries Sdn. Bhd**.** This company began operation in 1981 with the manufacture and export of desiccated coconut. In 1985, it became one of the first manufacturers in the country to mass market coconut milk powder.

Today, the company is producing high grade coconut products that are exported to about 30 countries in Asia, the Middle East, Europe and Australia with a potential volume up to 300 tonnes/ month. It is primarily involved in the processing of coconut into dried coconut milk powder, low fat desiccated coconut and non-dairy creamer.

The two main types of waste generated by this company are coconut skin, after the dehusking of raw coconut and coconut shell after the removal of the inner part (kernel), which is also called deshelling. Currently, both waste types are sold for manufacturing charcoal. Yet, this practice generally is not in line with the target to reduce GHG emissions. Therefore, alternatives which ensure a more environment friendly approach need to be implemented.

Besides coconut wastes generation through processing operations in coconut-based industry, abundant coconut waste is also generated in Malaysia from stalls where coconut juice is sold and the inner part is ground for coconut milk. This leaves the whole part of the coconut head as waste.

1.3 Waste Management Options in Coconut-Based Industry

For minimizing waste generation and preventing pollution, alternative methods have been introduced to treat different types of waste from agro-based industries. Waste audit is considered as an effective method for determining types and quantity of wastes that are being generated at each individual step within an organization. Information from waste audits will help to identify current waste practices and how they can be improved in terms of reducing waste management costs and better use of limited natural resources. Biological degradation of organic waste is considered one of the efficient processes to divert organic waste. This can be incorporated into the waste management system to tackle the organic waste problem in agro-based industries (Fauziah and Agamuthu, 2009). This includes treatment via a vermicomposting process. According to Suthar (2009), vermicomposting often results in mass reduction; a shorter time for processing and high levels of humus with reduced phytotoxicity. Vermicomposting of coconut waste is not only considered for enhancing waste reduction via biodegradation, but also for its usefulness when applied to agricultural soil to provide essential plant nutrients.

1.4 Problem Statement

Agricultural-based industries are becoming a more significant part of the economy of Malaysia. The increase in the number of agro-based industries not only affects the economy positively, but also contributes towards pollution. Also, a significant amount of post-processing waste and residue from these industries are being produced. Hence, it is important that new methods for treating agro-residues are adopted and considered in order to achieve sustainable management of agricultural waste. Coconut-based industry in Malaysia has been considered as part of the country's economic sector for a considerable period of time and has efficiently developed in recent years. Yet, this industry contributes to environmental degradation. In addition, large amounts of coconut waste are also generated that subsequently is thrown into landfills thereby taking up landfill space.

1.5 Objectives of Project

This project was carried out with the view to achieve the following objectives;

a) To identify and quantify the type of coconut waste generated from coconut-based industry.
b) To conduct waste audit in a selected coconut processing plant.
c) To assess the possibility of vermicomposting of different types of coconut waste.
d) To evaluate the potential of *Eudrilus eugeniae* to vermicompost coconut wastes.
e) To generate comparative data on the degradability of the various types of coconut waste.

CHAPTER 2 LITERATURE REVIEW

2.1 Solid Waste Generation- Global Scenario

Waste is defined as the unavoidable by-products of most human activities which are considered useless (http://www.wrap.org.uk, 2010). These wastes are normally solid, and the word *waste* suggests that the material is useless and unwanted (George, 2001). However, many of these waste materials can be reused, and thus they can become a resource for industrial production or energy generation, if managed properly (George, 2001). Economic development, rising living standards and human population growth contribute significantly to waste generation. The human population of the world on 30th March 2011 was estimated by the United States Census Bureau to be around 6,9 billion and this is believed to have led to increase in the quantity and complexity of generated waste (http://www.geohive.com, 2011). The increase in production to cope with the demand of an increasing population results in the generation of more waste. This requires proper management systems in order to mitigate undesirable side-effects on the environment (David and Bloom, 1995).

Environmental degradation has become one of the serious issues around the World which is believed to be closely related with resources consumption and waste generation (http://www.sos2006.jp, 2006). According to these reports, published by the World Resources Institute (WRI) in collaboration with Japanese and European research teams and by the Weight of Nations in 2000, resource efficiency per unit of economic output has been on the rise since the end of the 20th Century, but there is no evidence that overall resource consumption or waste generation is declining (http://www.sos2006.jp, 2006). Hence, waste management has become one of the most significant requirements of our time, mainly due to industrial diversification, generating enormous amounts of waste. Generally, people want to preserve their lifestyle, and at the same time like to protect the environment and public health (http://www.wrfound.org.uk/, 2009).

Waste management is defined as the collection, transport, processing, recycling or disposal, and monitoring of waste materials and the term usually relates to materials produced by human activity, and is generally undertaken to reduce their effect on health, the environment or aesthetics (http://www.wrfound.org.uk/, 2009). Waste management can involve solid, liquid, gaseous or radioactive substances, with different methods and fields of expertise for each. Waste management practices differ between developed and developing nations, urban and rural areas and residential and industrial producers (http://www.wrfound.org.uk/, 2009).

2.2 Solid Waste Generation - Malaysian Scenario

The management of solid waste is a continuous challenge in urban areas throughout the world, but particularly in the rapidly growing cities and towns of the developing countries (Zerbock, 2003). Global municipal solid waste generated in 1997 was about 0.49 billion tonne, with an estimated annual growth rate of 3.2–4.5% in developed nations and 2–3% in developing nations (Zahari *et al*., 2010). Rapid urbanization and industrialization changed the characteristics of solid waste generated which has resulted in the necessity of updating the solid waste management system (SWMS) to be compatible with the waste quality, quantity and composition (Zahari *et al*., 2010).

An efficient solid waste management system in developing countries displays an array of problems, including low or improper collection coverage and irregular collection services, open dumping, illegal dumping and burning, no air and water pollution control system, the breeding of flies and vermin, and the handling and control of informal waste picking or scavenging activities (http://www.sswm.info, 2008). As the urbanization rate is continually increasing, the management of solid waste is becoming a major environmental and public health problem in urban areas and these problems are caused by technical, financial, institutional, economic, and social factors which constrain the development of effective solid waste management systems (http://www.sswm.info, 2008). In developing countries, increasing waste production accompanies urbanization and the waste produced generally has a high moisture content and a low combustible fraction (e.g., paper and cardboard) (Ravi *et al*., 2009).

The Malaysian population is around 26,4 million as of 3rd Jan, 2011, due to the rate of 2.4% or about 600,000 per annum since 1994 (Zahari *et al*., 2010). Malaysia with a total land area of 328 550 km^2, generated about 30,000 tonnes per day of waste in 2009 (or 1.3 kg/capita/day) up from 18,000 tonnes in 2004 (Agamuthu and Nagendran, 2010). Information on the quantity of solid waste generated is fundamental in almost all aspects of solid waste management (Latifah *et al*., 2009). Most studies on municipal solid waste (MSW) generation used the load-account analysis, which is based on waste collected and disposed of in landfills (Latifah *et al*., 2009). Demographic factors and facilities, which are provided by the respective departments, caused the changes in waste generation rates (Latifah *et al*., 2009).

In Malaysia, MSW consists of industrial, domestic and agricultural waste. Daily MSW volume in Kuala Lumpur was 99 tonnes in the 1970s, but had increased rapidly to 587 tonnes in the 1990s and now it has exceeded 3200 tonnes (Agamuthu and Nagendran, 2010; Latifah *et al*., 2009). Currently in Malaysia, waste reduction and waste segregation are at a very low rate with recycling at only 3% to 5% (Mohamed *et al.*, 2009). Landfills are the major option and last fate for industrial, agrowaste and municipal solid waste in the country. Landfilling of these wastes is not a good alternative for treating and burying waste, rather it is cheaper than other ways. The lack of effective alternative methods in the waste management system results in 95% of the total waste generated in Malaysia being disposed into landfills (Fauziah and Agamuthu, 2009).

The total number of disposal sites throughout Malaysia is about 301, which include 41 closed facilities and 260 actively operating landfills, and the country is running out of land available for disposal because of the continuous increase in waste generation (Hamza *et al.*, 2011). The 3.6% annual increase in solid waste generation requires proper and advance facilities or technologies in order to mitigate the environmental degradation that might be caused by poor treatment methods utilized in the waste management system generally, and the disposal sites in particular (Fauziah, 2004). Sanitary landfills in Malaysia make up only 3% of the total existing disposal sites while the rest are non-sanitary landfill (Fauziah, 2004).

Many of the landfills in Malaysia are operating without proper lining for leachate collection, and leaked leachate treatment facilities (Jaffar *et al*., 2009). River pollution in Selangor in 2006 forced the government to take the decision to close 16 landfills immediately (http://www.wormfarming.co.za, 2006). Moreover, solid waste generation increases continually and has various impacts on the environment. Therefore, waste management options to minimize environmental degradation are vitally important. The following section discusses integrated solid waste management systems.

2.3 Waste Management Options

2.3.1 General View of Waste Management Options

The inevitable increase in MSW, including agrowaste, generation rate has obliged mankind to find proper and advance methods for waste management. This calls for waste collection process at various sources, i.e. either from industries, residential areas, commercial zones or institutions, followed by a pre-treatment stage before disposal. Currently some options are practiced as shown in Figure 2.1, such as recycling, material recovery, composting, anaerobic digestion, incineration and gasification, with landfilling as the last option in the waste management hierarchy (Agamuthu and Nagendran, 2010). In Malaysia, waste prevention has the least impact on the environment but a less practicable choice when compared to landfill which has the largest impact in terms of resource depletion and pollution intensity (Mohamed *et al.*, 2009). In developed countries, the organic fraction ranges between 25 and 45% so making composting more viable (http://www.medcities.org, 2000). Next section discusses more about adapting various methods to minimize the waste.

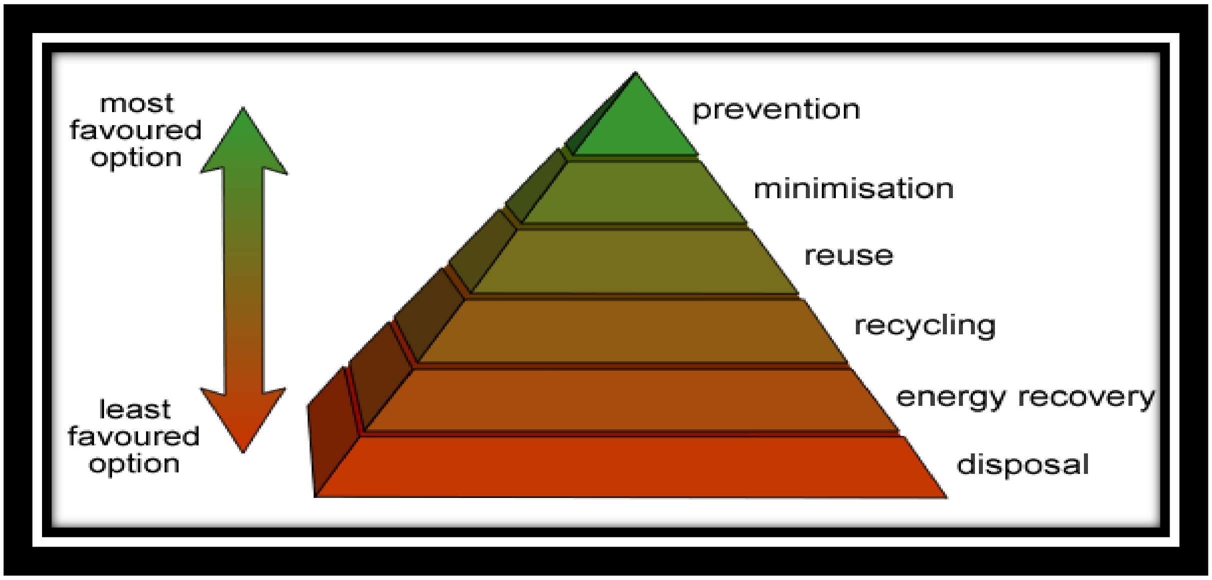

Figure 2.1: Hierarchy of Waste Management. (Source: http://www.aggregatepros.com)

2.3.2 Waste Minimization Program

Waste minimization is defined as the program which is being practiced in order to minimize the quantity of materials to be treated and disposed of and can be achieved usually through better product design (http://www.businessdictionary.com, 2010). Besides the significance of waste management system, the waste hierarchy as a part of waste management strategies has also taken many forms over the past decade, but the basic concept has remained as the cornerstone of most waste minimization strategies. The aim of waste hierarchy is to extract the maximum practical benefits from products and to generate the minimum amount of waste (William, 2005).

Some waste management experts have recently introduced a 'fourth R' (Re-think), by thinking that the current system may have fundamental flaws, and that a thoroughly effective system of waste management may need an entirely new way of looking at waste (http://www.netreuse.com, 2010). Source reduction involves efforts to reduce hazardous waste and other materials by modifying industrial processes, and some methods involved in waste reduction such as changes in manufacturing technology, raw material inputs, and product formulation (William, 2005). Moreover, this is reducing the toxicity and negative impacts of the waste that is generated, and also the reduction of waste at source, by understanding and changing processes as shown in Figure 2.2.

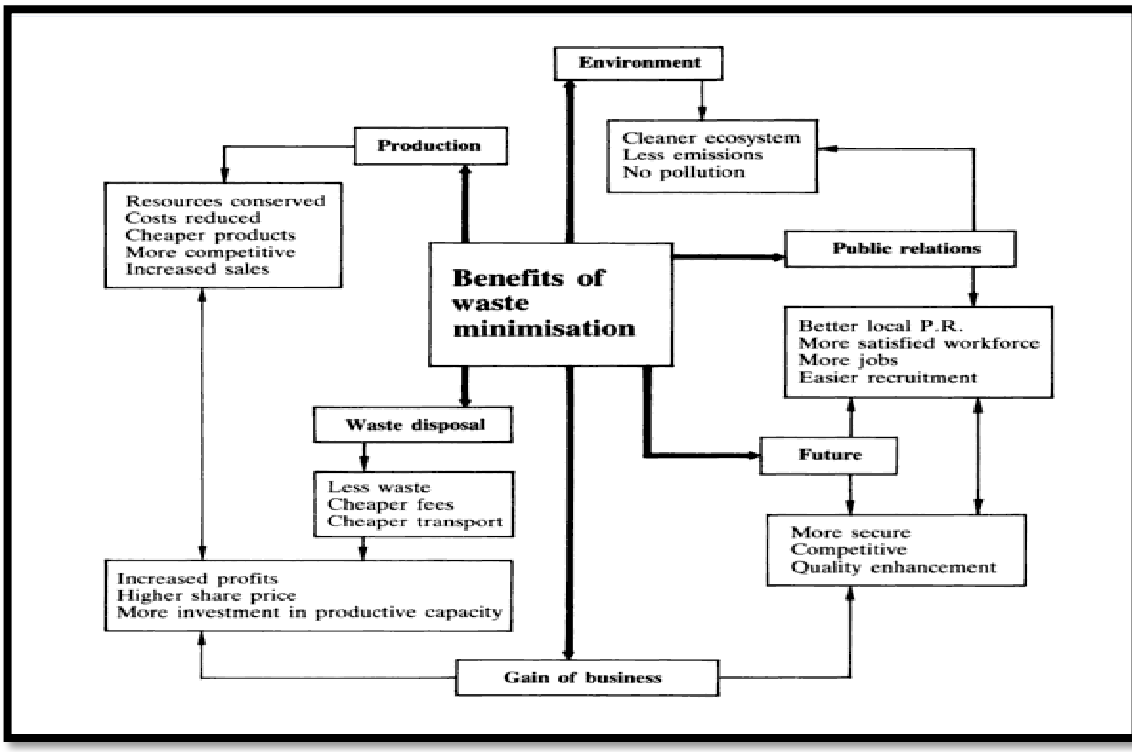

Figure 2.2: Various Advantages of Waste Minimization Program. (Adopted from James, 1995).

Waste minimization starts with waste prevention and reduction which is reducing the amount of waste that is created by choosing what rubbish would be thrown away. It is followed by reuse which is using an item more than once, that includes conventional reuse where the item is utilized again for the same function and new-life reuse. Reuse has certain potential advantages as shown below (http://www.recycling-guide.org.uk, 2003):

1. Energy and raw materials savings, since replacing many single use products with one reusable one reduces the number that need to be manufactured.
2. Reduces disposal needs and costs.
3. Cost savings for business and consumers as a reusable product is often cheaper than the many single use products it replaces.
4. Some older items were better handcrafted and appreciate in value.

Disadvantages are also apparent:

1. Reuse often requires cleaning or transport, which have environmental costs.
2. Some items, such as Freon appliances or infant auto seats, could be hazardous or less energy efficient if they continue to be used.
3. Reusable products need to be more durable than single use products, and hence require more material per item. This is particularly significant if only a small proportion of the reusable products are in fact reused.
4. Sorting and preparing items for reuse takes time which is inconvenient for consumers and costs more for businesses.

Recycling is the recovery of materials for use as direct or indirect inputs to new products. Recycling involves processing used materials into new products to prevent waste of potentially useful materials, and reduce the consumption of fresh raw materials. It also reduces energy usage, air pollution (from incineration), water pollution (from landfilling), and greenhouse gas emissions as compared to virgin production (http://www.recycling-guide.org.uk, 2003). Agricultural-based industries are accounted for generating considerable amount of waste despite its important as a source for evolving economy around the world (http://cpcbenvis.nic.in, 1994). Hence, the following section discusses the importance of agro-based industries particularly coconut-based industry, both globally and in Malaysia.

2.4 Agro-Based Industry

2.4.1 Agro-Based Industry Definition

Agro-based industry is one that increases the value of raw agricultural products through downstream processing so that products are marketable, consumable and used to generate income and provide profit to the producer (kamal *et al.*, 2009). Agro processing is a set of techno-economic activities carried out for conservation and handling of agricultural products to make it usable as food, fiber, fuel or industrial raw material.

A properly developed agro-processing sector not only encourages rural entrepreneurship, but can also make Malaysia a major supplier of processed food, feed and a wide range of other plant and animal products. Coconut-based industry is considered as one of the important agro-based industries and the following section discusses the role of the coconut-based industry scenario globally and in Malaysia.

2.4.2 Coconut -Based Industry –Global Scenario

Coconut plays an important role in Asian households and Malaysia is among the important producers of coconut in the world, as shown in Figure 2.3. It is estimated that 70% of coconuts produced in a country are used for domestic consumption of which more than half of the volume is consumed fresh (Ohler, 1999). The balance of the volume is consumed in the form of oil, edible or industrial (Ohler, 1999). In Indonesia, annual per capita consumption of coconut oil was about 3.5 kg in 2001 (or 4.8 and 2.2 kg for urban and rural consumers, respectively).

Nut availability per capita in the four most important producing countries was 10 for India, 53 for Indonesia, 156 for Sri Lanka, and 282 for the Philippines (Ohler, 1999). The residue of the oil extraction, the coconut cake, is a valuable feed for domestic animals and instead of harvesting the nuts, the sap of the inflorescences can be tapped for the production of sugar (Ohler, 1999). Coconut and palm kernel oil have a different fatty acid composition from other edible oils and both are relatively high in medium chain fatty acids, particularly lauric acid (Warne *et al*., 2007). Waste coconut oil has also been used for biodiesel production in Brazil (Felipe *et al*., 2010).

In addition, among several types of agricultural waste studied as biosorbents for water treatment, coconut waste has been utilized successfully for the removal of various aquatic pollutants due to its low-cost, as well as its significant adsorption potential for water treatment (Hernandez and Guerrero, 2008). In Sri Lanka, spent coconut flakes from coconut industries are being utilized to produce charcoal for the activated carbon industry (http://www.faculty.ait.ac.th, 2002).

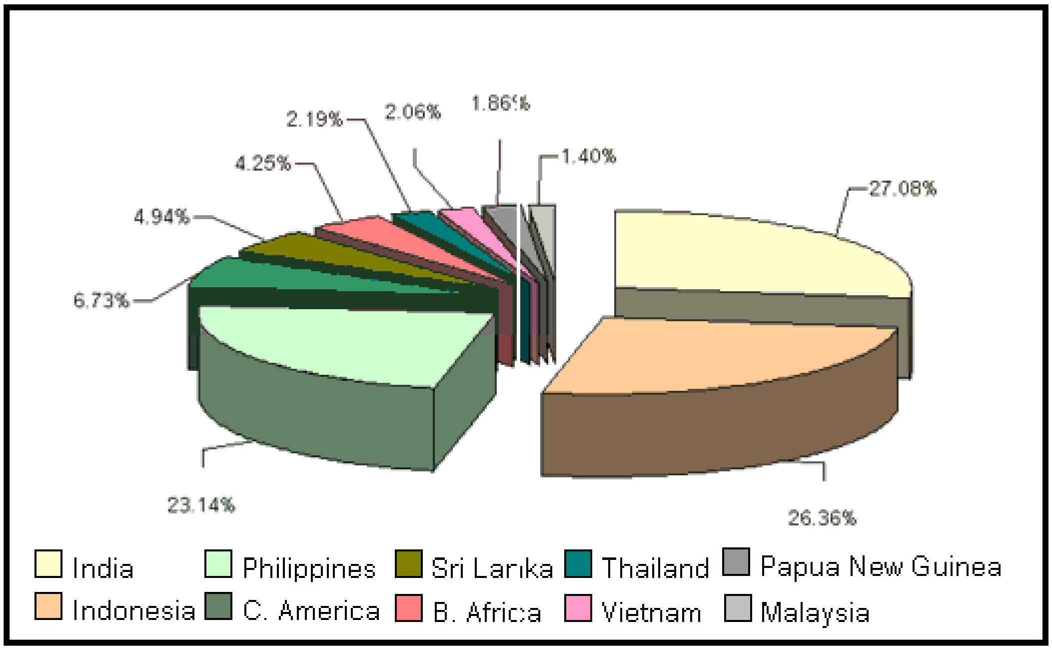

Figure 2.3: World Important Producers of Coconut in 1996.

Source: Statistical Yearbook 1966, Asian and Pacific Coconut Community (APCC).

In 2005, the European Union was the largest destination for coconut oil exports, accounting for 888 million tonnes, or just over 42% of world imports and the advent of modern small-scale processing technologies allowed for the commercial production of Virgin Coconut Oil (VCO) at the farm level (Etherington, 2006). Therefore, VCO is arguably the most useful vegetable oil in the world and VCO also has immediate medicinal, cooking, massage, cosmetic and fuel uses both for the local economy and for export. Coconut farmers were denied the privilege of coconut oil commercialization for decades as they were urged to produce copra for the export market (Etherington, 2006). Heavy metals, particularly zinc, can be removed from industrial wastewater by using modified activated coconut shell carbon changed with chitosan and oxidizing agent (phosphoric acid) to produce composite adsorbent (Bhatnagar *et al*., 2010).

In 1996, coconut palms covered 11 million hectares (ha) around the world of which about 93% was in the Asia-Pacific region. Among the major coconut producers in the world, Indonesia was the largest with around 3.7 million ha and second to that were the Philippines with 3.1 million ha as shown in Table 2.1. The third place, was India. Moreover, from among the countries in the South Pacific territories, Papua New Guinea stands out as the major producer, whereas Tanzania is the leading producer in Africa.

Table 2.1: World Growing Area of Coconut 1992-1996 (Unit: 1000 Hectares).

Country	1992	1993	1994	1995	1996
A. Asian and Pacific	10261	10244	10427	10555	10642
F.S. Micronesia	17	17	17	17	17
Fiji	65	65	65	64	65
India	1529	1538	1635	1714	1796
Indonesia	3599	3636	3681	3724	3745
Malaysia	315	310	305	290	280
Papua New Guinea	260	260	260	260	260
Philippines	3077	3075	3083	3064	3093
Solomon Islands	59	59	59	59	59
Sri Lanka	419	419	419	419	419

Source: Statistical Year Book 1996, Asian and Pacific Coconut Community (APCC).

2.4.3 Coconut Products

Desiccated coconut: is one of the coconut industries products that is widely produced. It is a grated, dried (3% moisture content), and unsweetened fresh meat or kernel of a mature fruit of coconut. Desiccated coconuts are cut into different grades, such as fine and medium, where fine grade has a smaller particle size than medium grade (http://www.harvardcocopro.com, 2010). The processing of desiccated coconut starts with the removal of the coconut husk as shown in Figure 2.4. It is followed by the removal of the shell and the thick brown skin. Further washing of white coconut meat is done to remove foreign material. Then it is blanched in order to reduce the number of microorganisms to a safe level fit for human consumption within its shelf life. The white coconut will be cut to a desired size and then hot air will be blown for drying the grated white coconut meat to reduce the moisture content from 19% to less than 3%. Finally, the desiccated coconut will be cooled and sieved to a desirable size and then packed. Approximately 1000 nuts will yield about 130kg of desiccated coconut (http://www.harvardcocopro.com, 2010).

In most cases, the value of desiccated coconut depends on the fat content. Hence, desiccated coconut is categorized into full fat (high fat) or reduced fat (low fat). A full fat desiccated coconut has a minimum of 60% fat, while less than that is considered as a reduced fat desiccated coconut. Full fat desiccated coconuts have higher monetary value than the reduced fat. In the past, coconut fat or coconut oil has been mistakenly believed to cause heart disease (http://www.harvardcocopro.com, 2010).

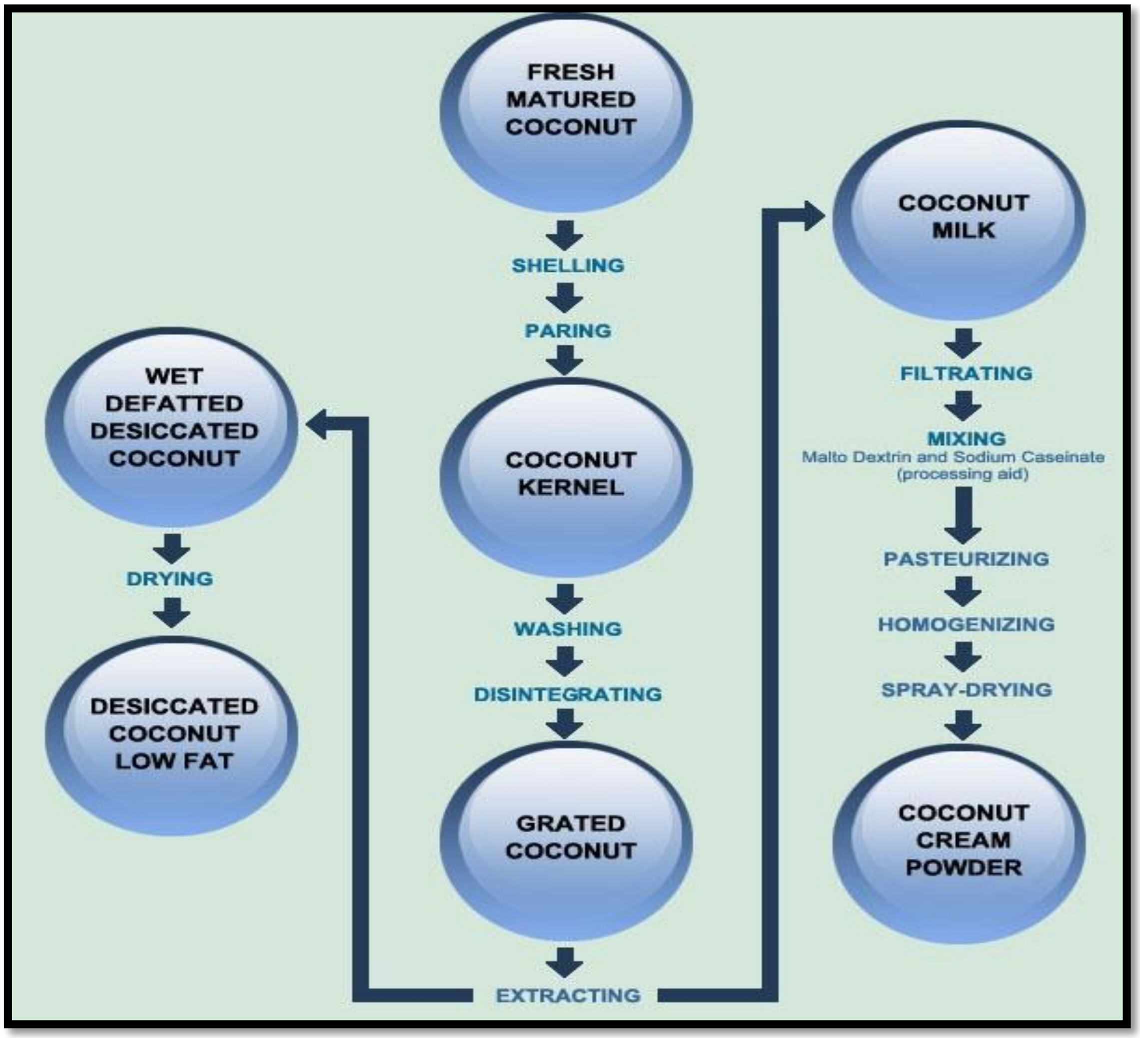

Figure 2.4: Desiccated Coconut (DC) Process Flow Diagrams.

Source: http://www.stancodex.com, 2010).

Virgin Coconut Oil (VCO): is derived from the fresh meat or kernel of a mature coconut rather than the sundried coconut meat which is known as copra. It can be produced in one of two ways:

1. Quick drying of fresh coconut meat, which is then used to extract the oil by mechanical means.

2. Wet-milling method. Coconut milk is first extracted from fresh coconut meat by mechanical pressing. The oil is then extracted from the coconut milk by boiling, fermentation, refrigeration, enzymes or mechanical centrifuge.

Coconut Milk or Cream production: Coconut milk or cream refers to the oil-protein-water emulsion which can be prepared by squeezing grated fresh coconut kernel, as shown in Figure 2.4. In Asian and Pacific households, the undiluted and diluted forms are referred to as coconut milk and the concentrated form as coconut cream, but with industrial processing and exports of this product during the past 20 years, all forms are currently referred to as coconut cream (Ohler, 1999).

In coconut-producing countries, coconut cream is processed in households (without industrial processing) and used for cooking and baking traditional food, whereas in importing countries, it is mainly utilized for preparing meat, fish and poultry dishes, sauces, salads, curries, seafood, desserts, cocktails, cakes, candies, cookies, coconut Jam and ice cream.

2.4.4 Coconut – Based Industry - Malaysia Scenario

The agricultural sector has registered favourable growth in Malaysia due to its equatorial climate and fertile soil. Also, the Eighth and Ninth Malaysian Plan encouraged the growth of agriculture and agro-based industry from 2001 to 2005 and also from 2006 to 2010 (http://www.mtc.com.my, 2006). Development from export earnings of the agricultural sector in Malaysia was predicted to expand significantly under this plan due to the increase in export volume and better prices of agro-based industries commodities. The sector has continued to provide the raw materials required by the domestic agro-based industries (http://www.epu.gov.my, 2009). In addition, the agricultural sector is expected to grow at a higher average annual rate of 5.0% and with the inclusion of the agro-based industry; the growth rate is expected to be 5.2% (http://www.mtc.com.my, 2006). The production of agricultural commodities, except cocoa and pepper, continued to record positive growth, because of higher prices and market expansion, as well as the effective implementation of programmes and projects to improve productivity and quality of outputs (http://www.mtc.com.my, 2006).

The agro-based industry grew at 4.5% per annum in Malaysia and its total export earnings increased significantly by 8.7% per annum to reach RM37.4 billion in 2005 (http://www.epu.gov.my, 2009). The processing of end-products from agro-based industries commodities, such as palm oil, rubber and cocoa, increased during this period. The coconut industry in Malaysia has recently received new interest among agriculture policy makers in the country. It is no longer labelled as a sunset industry; instead it has been identified as a strategic crop after oil palm, rubber and paddy. Currently, it is considered as one of the new emerging industrial crops that could bring a significant impact on the country’s economy. With the new emphasis given, the industry was allocated a significant amount of funds in 2009, RM29.0 million, in order to uplift and rejuvenate the whole industry (http://www.epu.gov.my, 2009).

The second part of the Ninth Malaysian Plan, from 2006 to 2010, (Table 2.2) comprised the overall policy thrusts of the agricultural sector in Malaysia which focus on creation of high-income farmers, as well as promotion of greater private sector investment including foreign investment and its reorientation towards greater commercialization (http://www.epu.gov.my, 2009). Hence, in this regard, the policy thrusts will be as follows:

1. Increasing agricultural production by venturing into new sources of growth with greater private sector participation;
2. Expanding agro-based processing activities and product diversification;
3. Strengthening marketing and global networking;
4. Enhancing incomes of smallholders, farmers and fishermen; and
5. Improving the service delivery system.

Coconuts have become one of the most important crops in the Asia Pacific region. It plays a significant part in the local economy and culture, not only for large producers such as the Philippines, India and Indonesia, but also in the Pacific Islands, where coconut palms are integral to the livelihoods of many smallholders as almost 90% of the total world coconut production occurs in this region (Warne *et al*., 2007).

Table 2.1: Production of Agricultural Commodities, 2000-2010.

commodity	Agricultural production (Metric Tonnes)			Average Annual Growth Rate (%)		
	2000	**2005**	**2010**	**8MP**		**9MP**
Industrial Commodities				**Target**	**Achieved**	**Target ***
Rubber	928	1,124	1,293	4.0	3.9	2.8
Crude Palm Oil	10,842	14,961	19,561	6.1	6.7	5.5
Palm Kernel Oil	1,384	1,868	2,570	5.0	6.2	6.6
Food Commodities						
Padi	2,141	2,400	3,202	0.2	2.3	5.9
Fisheries	1,454	1,575	2,071	7.2	1.6	5.6
Marine	1,286	1,325	1,409	5.9	0.6	1.2
Beef	17.5	28.5	45.0	18.0	10.2	9.6
Mutton	0.9	1.5	2.3	11.0	10.8	8.9
Miscellaneous						
Pepper	24.0	19.1	30.0	5.9	- 4.5	9.5
Vegetables	404.0	771.3	1,133.3	0.6	13.8	8.0
Coconut	475.7	602.0	660.0	0.6	4.8	1.9
Fruits	993.0	1,586.9	2,555.7	3.1	9.8	10.0

Source: Ministry of Agriculture and Agro-Based Industry and Ministry of Plantation Industries and Commodities (2006).

* No data was available for achievement.

Based on the report published by the Australian Centre for International Agricultural Research in 2007, coconut production around the world appears to have been growing at around 2% a year since the early 1960s (Table 2.3). However, production of copra and coconut oil has stagnated, as palm oil and soybean oil have grown to dominate world markets for edible oils (Bob Warne, 2007). The bulk of coconuts are consumed domestically for food. For the Philippines and producers in the Pacific, most coconuts are processed into copra for further processing into oil.

Table 2.3: Agricultural Land Use, 2000-2010.

Crop	Agricultural land use (hectares)			Average Annual Growth Rate (%)		
				8MP		**9MP**
	2000	**2005**	**2010**	**Target**	**Achieved**	**Target**
Oil palm	3,377	4,049	4,555	3.2	3.7	2.4
Rubber	1,431	1,250	1,179	-2.7	-2.7	-1.2
Padi	478	452	450	-0.5	-1.1	-0.1
Fruits	304	330	375	5.1	1.7	2.6
Coconut	159	180	180	-0.6	2.5	0.0
Cocoa	76	33	45	-2.4	-15.2	6.2
Vegetables	40	64	40	4.2	9.9	6.1
Total	5,893	6,383	6,891	1.5	1.6	1.5

Source: Ministry of Agriculture and Agro-Based Industry and Ministry of Plantation Industries and Commodities.

Since, coconut is one of the main important crops due to its usage in different types of products, a considerable amount of waste is generated during coconut processing, and conducting waste audit is necessary to identify and quantify the waste being generated. The following section discusses the waste audit process and its significance to minimize waste generation from unit processes.

2.5 Waste Audit

A waste audit is a formal, structured process which requires various elements to quantify the amount and types of waste being generated by an organization. Information from audits helps identify current waste practices and how they can be improved (Jennifer, 2010). Waste audit is carried out for the purpose of achieving a more efficient and effective organization; reduce waste management costs, and better use of limited natural resources. Moreover, waste audit needs to be conducted in order to minimize the waste generated, as well as to avoid unnecessary cost for the waste management program.

Audits can be done on any type of waste (e.g. paper and office waste, municipal waste, commercial and industrial waste, construction and demolition waste). There are a number of different ways to conduct a waste audit, such as visual waste audits, waste characterization, and desktop audits. The type of audit used depends on the type of waste and where it is to be conducted (http://www.epu.gov.my, 2009).

The waste minimization process starts with a waste audit and during the waste audit process, each operation should be examined in order to determine how the waste from each step is generated, what are the characteristics, how can it be managed and what will be the cost (http://www.ehs.umaryland.edu, 2005). Moreover, important and necessary data are acquired to prioritize which one of the waste streams will be treated first and identify alternative options for minimizing the high-priority waste (Fernando and Maria, 2009). The prioritization is generally determined based on some important criteria, such as waste composition, quantity, cost of disposal, degree of hazard, potential for minimization, recycling and compliance status (Fernando and Maria, 2009).

A typical waste audit should contain the following steps (Agamuthu, 2001):

Step 1: Determine the types and amounts of hazardous substances in waste stream and emissions, including regulated and unregulated.

Step 2: Identify the specific production sources of the wastes and emissions.

Step 3: Set priorities for waste minimization process based on cost, environmental concern, worker’s health and safety, liabilities, and production constraints.

Step 4: Alternatives for waste minimization should be analyzed technically and economically.

Step 5: Make a comparison between current waste management techniques with the alternative techniques in terms of economy.

Step 6: Evaluate and study the progress and success of selected alternatives for waste minimization and organize the techniques or options periodically based on the review.

Four important stages of waste reduction audit have been suggested assess the applicability of waste audit process at the following points (Agamuthu, 2001).

First stage: Common sense waste reduction

During this stage, immediate and visible reduction options are considered. Common sense and low cost are two main criteria to be identified through direct observation of the operating process. There are no technical barriers and it can be implemented in days and weeks. As a result, usual procedures are changed rather than changes in production technologies or major equipment. This approach can provide the staff with more information and record of actions and results.

Second stage: Information-derived waste reduction

This approach is considered to be easy, low cost, and quick, with no significant technological obstacles. But it requires more detailed information about the generation of waste. During this stage, simple changes in production are made which are prompted by production from similar successful industries. For example, replacing an organic solvent with a water-based solvent and installing a closed-loop cycling unit.

Third stage: Audit dependent waste reduction

In this stage, formal waste audit is important, where technical and economical feasibility need to be evaluated and technical obstacles are identified. Uncertainty about economic payback and technical feasibility is characteristic of this stage, as profitable payback will probably take a long time. Waste reduction can become integrated with major processes and product improvements. Sometimes external consultants should contribute to overcome the obstacles to waste reduction.

Forth stage: Research and development-based waste reduction

Extensive studies and research on process technology or equipment, and product composition or even design modification is required at this stage. Careful and continuing economic analyses are required. Moreover, waste reduction audit needs to be conducted periodically for both the original situation and any new waste generation from the research and development activities.

In addition, from each production process various types of waste rise up and so the waste should be quantified and identified via conducting waste audit. The appropriate technology is vitally important in order to improve the quality of the environment, such as methods of recycling organic compounds which is named bioconversion. The following section discusses bioconversion of organic waste.

2.6 Bioconversion

Bioconversion is defined as the degradation and conversion of material from a complex form to less complex form by utilizing living organisms. In this type of recycling, the waste materials, particularly organic compounds, are converted to useful by-products like compost and the volume of waste sent to landfills is also highly reduced. Moreover, the reduction of greenhouse gases emissions from landfills is also achieved via bioconversion (Ruzena**,** 1998). The most common forms of bioconversion which are widely practiced throughout the world are composting and vermicomposting. These processes require degradation activities by decomposers including bacteria, fungi, actinomycetes and various protozoa, under aerobic condition to produce a pathogen-free yield.

However, composting is somewhat impractical with household waste due to the small quantity of organic waste produced by individual households. The generation rate of Malaysian household organic waste averaged only 0.9kg/day/family and rapid degradation is enhanced by the climatic factor. The alternative option to conventional composting is vermicomposting which works efficiently in processing smaller quantities of organic matter (http://www.howtocompost.org, 2010).

2.6.1 Vermicomposting

Vermicomposting is defined as the process where earthworms are utilized for digesting and breaking down the organic components and through the vermicomposting, organic wastes are decomposed into odor free humus-like material (Suthar, 2009). Vermicomposting has been practiced by developed countries worldwide as an effective way of reducing the volume of waste disposal to landfill (Abdul, 2010). There are several species of worm used in the vermicomposting process such as *Eisenia foetida, Lumbricus rubellus, Perionyx excavates*, *Lampito manuritii*, *Eudrillus euginea*, and *Pheretima elongate* (Fauziah and Agamuthu, 2009; Nair *et al*., 2006; Tripathi and Bhardwaj, 2004). Vermicompost contains not only worm castings, but also bedding materials and organic wastes like kitchen waste at various stages of decomposition (George, 2001). Also, it has been found that vermicomposting contains worms and other microorganisms associated with the composting process at various stages of development (Manuel and Jorge, 2010). Earthworm castings in home gardens often contain 5 to 11 times more nitrogen, phosphorous and potassium than the surrounding soil (George, 2001). Secretions in the intestinal tracts of earthworms, along with soil passing through the earthworms, make nutrients more concentrated and available for plant uptake, including micronutrients. Nutrients in vermicompost are often much higher than traditional garden compost (George, 2001). Red worms in vermicompost act in a similar fashion, breaking down food wastes and other organic residues into nutrient-rich compost.

2.6.2 Anatomy of Earthworms

The earthworm has a long, rounded body with a pointed head and slightly flattened posterior. Rings that surround the moist, soft body allow the earthworm to twist and turn, especially since it has no backbone. With no true legs, bristles (setae) on the body move back and forth, allowing the earthworm to crawl (Edwards, 2004). The earthworm breathes through its skin while food is ingested through the mouth into a stomach (crop). Later, the food passes through the gizzard, where it is ground up by ingested stones. After passing through the intestine for digestion, what is left is eliminated. Earthworms are hermaphrodites, which mean they have both male and female sex organs, but they require another earthworm to mate. The wide band (clitellum) that surrounds a mature breeding earthworm secretes mucus (albumin) after mating. Sperm from another worm is stored in sacs. As the mucus slides over the worm, it encases the sperm and eggs inside (Edwards, 2004).

After slipping free from the worm, both ends seal, forming a lemon-shape cocoon approximately 1/8 inch long. Two or more baby worms will hatch from one end of the cocoon after approximately 3 weeks. Baby worms are whitish to almost transparent in colour and are 1/2 to 1 inch long (Edwards, 2004). Red worms take 4 to 6 weeks to become sexually mature. Earthworms have been classified in several ways; with perhaps the most useful based on their behaviour and habitat. The worms are divided into the following three categories: epigeic, endogeic, and anecic (Edwards, 2004).

1. Epigeic – live at the surface in freshly decaying plant or animal residues.
2. Endogeic – live underground and eat soil to extract nutrition from degraded organic residues.
3. Anecic – burrow deep in the soil but come to the surface at night to forage for freshly decaying organic matter.

Several epigeic earthworms, e.g., *Eisenia fetida*, *Perionyx excavatus*, *P. sansibaricus*, *Eudrilus eugeniae* and *Eisenia andrei*, have been identified as detritus feeders and can be used potentially to minimize the anthropogenic wastes from different sources (Asha *et al*., 2006; Suthar and Singh, 2008). But *E. fetida* was, and still remains, the favoured earthworm species for laboratory trial experiments on vermicomposting due to its wide tolerance of environmental variables (pH, moisture content, temperature, etc.). Some tropical and native Indian earthworm species, e.g., *P. excavatus, P. sansibaricus, E. eugeniae*, and *Lampito mauritii*, have also been used in the vermicomposting of organic wastes to produce bio-fertilizer (Suthar, 2009) but their narrow tolerances of environmental variables make them less attractive for vermiculture trials.

The earthworm species, *P. ceylanensis* is a potential vermicomposting species and the vermicompost produced by using this worm had a very good effect on plant growth and yield (Edwards et al., 2010). While investigating the efficiency of *L. mauritii* and *P. ceylanensis* for vermicomposting, different organic substrates and both the earthworm species can be used for vermicomposting; however, the duration of vermicomposting with *P. ceylanensis* is not as much as *L. mauritii* (Natchimuthu and Thilagavathy, 2009).

Eudrilus eugeniae is commonly known as African nightcrawler and is a semi-tropical species, meaning it cannot easily tolerate or adapt to cool temperatures and is usually grown indoors or under temperature controlled conditions (http://ternakancacingmelaka.blogspot.com, 2008). *E. eugeniae* is a large species, well suited for use as a bait worm, but does not tolerate handling or disruption to its environment. This species is used in some vermicomposting systems around the Mediterranean region and in some areas of eastern Asia. Hence, the worms can survive under the temperature range of minimum 7°C, maximum 32°C. The ideal range is 21°C to 26°C and the reproductive rate is approximately 7 young per worm per week under those ideal conditions (http://ternakancacingmelaka.blogspot.com, 2008). In addition, time to sexual maturity is from 30 to 95 days under ideal conditions (http://ternakancacingmelaka.blogspot.com, 2008).

Chicken, sheep and cow dung are the most favourable wastes for the growth and reproduction of *E. eugeniae*, and hence can be recommended as feed materials in large scale vermicomposting facilities (Coulibay *et al*, 2010). Epigeic (phytophagous) species like *E. eugeniae* have very shallow burrows in which they lie during the day, being nocturnal animals; their feeding activity is brisk only during the night when they pull the feed from the surface and ingest it in their burrows (Gajalakshmi, Ramasamy and Abbasi, 2002).

Earthworms in the epigeic category are most commonly used in vermicomposting and the species of worm that is usually associated with processing organic materials is *Eisenia fetida* (commonly known as red wiggler, tiger worm, or brandling worm) which can be found in areas of decaying vegetation such as fallen leaves, manure piles, or under rotting logs (http://mypeoplepc.com, 2010).

The advantages of vermicomposting are pointed out below (http://www.wormfarming.co.za, 2010).

1. Vermicompost is rich in all essential plant nutrients.
2. Provides an excellent effect on overall plant growth as it encourages the growth of new shoots/leaves and improves the quality and shelf life of the produce.
3. Vermicompost is free flowing, easy to apply, handle and store and does not have a bad odour.
4. It improves soil structure, texture, aeration, and water holding capacity and prevents soil erosion.
5. Vermicompost is rich in beneficial micro-flora such as fixers, P-solubilizers, cellulose decomposing micro-flora etc, in addition to improved soil environment.

6. Vermicompost contains earthworm cocoons and increases the population and activity of earthworms in the soil.

7. It prevents nutrient losses and increases the use efficiency of chemical fertilizers.

8. Vermicompost is free from pathogens, toxic elements, weed seeds etc.

9. Vermicompost minimizes the incidence of pests and diseases.

10. It enhances the decomposition of organic matter in soil.

11. It contains valuable vitamins, enzymes and hormones like auxins, gibberellins etc.

Organic waste can be utilized efficiently in vermicomposting with additives like cow dung (Kaviraj and Sharma, 2003). The purpose of using cow dung is only as a supplement and also as bedding material for the earthworms at an early stage before they climatize with the treatments given (Kaviraj and Sharma, 2003). Pre-composting for 21 days has shown that earthworms can be protected from being exposed to high temperature during the initial thermophilic stage of composting (Nair *et al*., 2006).

The action of earthworms in the process of vermicomposting of waste is physical and biochemical. The physical process includes substrate aeration, mixing, as well as actual grinding, while the biochemical process is influenced by microbial decomposition of substrate in the intestines of earthworms (Kaviraj and Sharma, 2003). Vermicomposting of organic waste accelerates organic matter stabilization and gives chelating and phytohormonal elements which have a high content of microbial matter and stabilized humic substances (Singh and Sharma, 2002).

The existence of fungi during vermicomposting becomes the additional supplement to the earthworms as it contributes to the increasing number and weight of the earthworms. Fungi have cell walls composed of chitin that contains a high level of natural protein; amino polysaccharide (Adi and Noor, 2009). Earthworms acquired weight when reared in cultures of certain fungal species, and in particular, protozoa and fungi are assumed to form a substantial part of their diet (Adi and Noor, 2009).

Acid production is initiated by the microorganisms during organic matter decomposition, which is the major mechanism or factor for solublisation of insoluble Phosphorous (P) and Potassium (K) (Kaviraj and Sharma, 2003). Therefore, the presence of a large number of micro-flora in the guts of earthworms is believed to play a significant role in increasing P and K content in the process of vermicomposting (Nair and Okamitsu, 2010). The P content indicates a direct action of earthworm gut enzymes and indirect stimulation of the microflora due to bacterial and faecal phosphate activity of earthworms that probably leads towards mineralization and mobilization of phosphorus (Nair and Okamitsu, 2010).

Other micronutrients like Na, Zn, Cu, Fe, Mn, and B are classified as trace elements which are required by plants in very low concentrations for adequate growth and reproduction. Despite their low concentrations within the plant tissues and organs, micronutrients play an important role and are essential for the growth and development (Fauziah and Agamuthu, 2009). The percentage difference for micronutrient elements in vermicompost based on different kinds of treatment are only in small ranges. The analysis of crude fat in vermicompost can be an indicator to determine the stabilization of waste used as feed materials in vermicomposting (Adi and Noor, 2009).

Confrontations between indigenous and foreign organisms usually occur when different worm species are being used and it is unnecessary and undesirable to tamper with local biodiversity (Kaviraj and Sharma, 2003).

The electrical conductivity (EC), or specific conductance is a measure of a material's ability to conduct an electric current and a gradual increase in EC gives increase in decomposition time (Kaviraj and Sharma, 2003). A gradual increase in EC during decomposition time in vermicomposting occurs due to the loss of weight of organic matter and release of different mineral salts in available forms (such as phosphate, ammonium, and potassium) (Kaviraj and Sharma, 2003). The increase in earthworm population takes place due to the C-to-N ratio decreasing with time (Ndegwa and Thompson, 2000).

The epigeic species of earthworms (i.e. *E. fetida*) are capable of working hard to convert all the organic waste into valuable by-products, but are of no significant value in modifying the structure of soil. The anaecic species (like *L. mauritii*) are capable of organic waste consumption as well as modifying the soil structure (Adi and Noor, 2009).

2.6.3 Chemical Parameters and Microorganisms in Vermicomposting

Carbon to nitrogen ratio has an important impact and it is also considered as a major parameter in vermicomposting (Ndegwa and Thompson, 2000). In order to provide proper nutrition, N and C must be present in the substrate at the correct ratio and the role of organic C and inorganic N for cell synthesis, growth and metabolism in all living organisms, is critical. An appropriate C-to-N ratio for optimal earthworm digestion is necessary too (Ndegwa and Thompson, 2000). The conventional determination of C-to-N ratio is usually based on the absolute contents of both C and N in the feed materials and not necessarily on what proportion of each nutrient are available for these processes and for the purpose of establishing optimal C-to-N ratio (Ndegwa and Thompson, 2000).

High C-to-N ratio, indicated by high C, decreased biological activity resulting in slow degradation (Nair *et al*., 2006). The changes in C-to-N ratio in thermocomposting normally occurs by the loss of C as carbon dioxide, while in vermicomposting, in addition to loss of C, the increase in the N content of the substrate due to microbial and enzymatic activity also influences the reduction of the C-to-N ratio (Nair *et al*., 2006).

The increase in organic C during vemicomposting is due to the formation of earthworm casts, which are rich in organic C and this indicates that the process of vermicomposting is complete (Nair *et al*., 2006). The increase in amounts of N, P and K in the vermicompost indicates that there is enhanced mineralization of these elements. This is defined in biology as the process where an organic substance is converted to an inorganic substance like N which is only available to plants in the inorganic form due to microbial and enzyme activity in the guts of the earthworms (Nair *et al*., 2006).

Total N content is increased due to C loss with significant differences between the treatments and the loss of dry mass (organic carbon) in terms of CO_2, as well as water loss by evaporation during mineralization of organic matter which determined the relative increase in N (Nair *et al*., 2006). In general, the final content of N in vermicomposting is dependent on the initial amount of N present in the waste and the extent of decomposition.

Furthermore, decrease in pH is an important factor in N retention as this element is lost as volatile ammonia at high pH values (Kaviraj and Sharma, 2003).

Microbial decomposition occurs simultaneously with vermicomposting. The microflora living in an earthworm's intestines, and those in the growth medium, enhance the decomposition process of the substrates. The intestinal mucous, which consists of easily metabolizable compounds, is considered to result in a priming-effect of earthworms to microbial decomposition (Ndegwa and Thompson, 2000). Some earthworms utilize microorganisms in their substrates as a food source and can digest them selectively (Singh and Sharma, 2002). The efficiency of vermicomposting depends on the number and types of microorganisms in the substrate (Ndegwa and Thompson, 2000). Microbial decomposition is further known to occur best when the C-to-N ratio of the substrate is approximately 25 (Ndegwa and Thompson, 2000).

Vermicomposting is also considered as a process microbiologically characterized by strong changes in microbial biomass with periods of rapid growth, as well as low activity, unlike the steady-state situation of most soils (Aira and Dominguez, 2010). It has been shown that microbial biomass and activity decreases during vermicomposting, despite enhancement of both microbial parameters at an initial stage (Manuel and Jorge, 2010). In addition, vermicomposting also produces considerable changes in physic-chemical properties of substrates (like pH, N and C pools), making the fine-tuning of analytical procedures to study microbial communities characteristics, like microbial biomass and substrate induced respiration, difficult (Manuel and Jorge, 2010).

The qualitative approach is utilized to determine the significance of C-to-N ratio with respect to population and distribution of earthworms in their natural ecology. The practice is being used to arbitrarily add a carbonaceous base if the material in question is too nitrogenous (Ndegwa and Thompson, 2000). Agrowaste from the cotton industry is utilized to qualitatively balance and improve the C-to-N ratio of the feed substrate (Ndegwa and Thompson, 2000).

The chemical analysis projects *E. fetida* to be superior in performance over *L. mauritii,* in terms of loss of TOC, reduction in C-to-N ratio and increase in EC and TK (Kaviraj and Sharma, 2003). The following parameters are determined for the feed: moisture content, pH, volatile solids (VS) and ash content. These analyses are either carried out immediately after the samples are obtained, or refrigerated at 4°C to minimize microbiological decomposition until analysed (Ndegwa and Thompson, 2000).

Some earthworm species can be used efficiently to consume a wide range of organic wastes such as sewage sludge, animal dung, crop residues and industrial refuse (Asha *et al*., 2006). Earthworms fragment the waste substrate and accelerate rate of decomposition of the organic matter, leading to a composting effect through which unsterilized organic matter becomes stabilized. The vermicompost has more available nutrients per kg weight than the organic substrate from which it is produced (Asha *et al*., 2006). The biological activity of earthworms provides a nutrient rich vermicompost for plant growth, thus facilitating the transfer of nutrients to plants (Asha *et al*., 2006).

Vermicomposting can significantly modify the physical and chemical properties of different feed mixtures and also lower the pH in the final products through the production of CO_2 and organic acids by microbial metabolism during decomposition of different substrates in the feed mixtures (Raphael and Velmourougane, 2010). Furthermore, different substrates could result in the production of different intermediate species resulting in different behaviour in pH shift and organic C decreases more significantly with time in all the feed substrates as compared to control (Asha *et al*., 2006). Increase in N content in the final product (vermicast) in the form of mucus, nitrogenous excretory substances, growth stimulating hormones and enzymes from earthworms takes place (Garg and Renuka, 2009).

Earthworms also have a great impact on N transformations in manure, by enhancing N mineralization, so that mineral N may be retained in the nitrate form (Rola *et al*., 2000). Also, available P and TK increase significantly in all the substrates with worm inoculated waste than in treatments without earthworms. An increase of 25% in P of paper waste sludge, after worm activity, is attributed to direct action of worm gut enzymes and indirectly by stimulation of the microflora (Krishnamoorthy, 1990). Increase in P during vermicomposting occurred due to mineralization and mobilization of phosphorus as a result of bacterial and faecal phosphatase activity of earthworms. TK was also higher in the final product than in the initial feed substrates, indicating that the microbial flora also influences the level of available potassium and acid production by the microorganisms. It seems to be prime mechanism for solubilizing the insoluble K (Asha *et al*., 2006).

Wheat straw is utilized to test the technical viability of an integrated system of composting with bioinoculants and subsequent vermicomposting, to overcome the problem of lingo-cellulosic waste degradation, especially during the winter season (Singh and Sharma, 2002). The combination of the thermocomposting and vermicomposting is to improve the treatment efficiency and assess the optimum period required to produce good quality compost (Singh and Sharma, 2002). Furthermore, vermicomposting can achieve safe pathogen levels which may be facilitated by the microbial and enzymatic activity with an added advantage of converting the important plant nutrients into a more soluble state, helping plant utilization (Nair *et al*., 2006). The reduction in waste volume also occurs during thermocomposting which reduces the area of worm bed that is required and reduces the time required for vermicomposting (Singh and Sharma, 2002).

Some species are identified as potentially useful to break down organic wastes, which are *Eisenia fetida*, *Dendrobaena veneta* and *Lumbricus rubellus* from temperate areas and *Eudrilus eugeniae* and *Perionyx excavatus* from the tropics (Elvira *et al*., 1998). The survival, growth, mortality and reproduction of these species have successful results with a wide range of organic wastes (Edwards, 2004). An African earthworm, *Eudrilus eugeniae*, is employed for degradation of organic wastes and the casts obtained are used as bio-organic fertilizer (Tripathi and Bhardwaj, 2004).

E. fetida produces a faster change in organic waste plus cow dung vermicompost with moderate mineralization, higher decomposition rates, and moderate breeding. *L. mauritii* produced moderate mineralization and moderate decomposition rates with moderate breeding (Tripathi and Bhardwaj, 2004). Both earthworm species differ in rates of decomposition and mineralization but not in the trend of decomposition (Tripathi and Bhardwaj, 2004).

Vermicomposting of vegetable-market solid waste using *Eisenia fetida*, and finding the impact of bulking material on earthworm growth and decomposition rate is considered to be possible (Suthar, 2009). Microbes are responsible for the biochemical degradation of organic matter and earthworms are the important drivers of the process, conditioning the substrate and altering the biological activity. Suthar (2009) and Dominguez (2004) described the vermicomposting process as where, “earthworms act as mechanical blenders, and by accumulating the organic matter, they modify its biological, physical and chemical status, gradually reducing its C-to-N ratio, increasing the surface area exposed to microorganisms, and making it much more favourable for microbial activity and further decomposition”. In vermibeds, earthworms maintain aerobic conditions in the organic wastes, ingest solids, convert a portion of the organics into worm biomass, and expel the remaining partially stabilized product, i.e., vermicast.

The vermicomposting offers a better quality product than traditional composting systems in terms of nutrient availability (Suthar, 2009). Since the organic matter is transferred differently in compost and vermicompost, it can be partly explained by methods adopted for waste transformation (Suthar, 2009). There is evidence of successful utilization of earthworms for stabilization of anthropogenic wastes generated from different industries (Elvira *et al*., 1998). Phosphorus mineralization varied significantly among different vermibeds possibly due to quality and proportion of bulky materials in feedstock and also if organic matter passes through the guts of earthworms, it results in some amount of phosphorus being converted with more availability to plants (Suthar, 2009). The difference among vermireactors for P mineralization rate could be due to different chemical structures of substrate material (Suthar and Singh, 2008). When passed through the gut of a worm, some quantity of organic minerals are converted into more available forms through the action of enzymes produced by gut associated microflora (Suthar, 2009). The vermicomposting process accelerates the microbial populations in waste and subsequently enriches the end product with more available forms of plant nutrients (Suthar, 2009). Bulky material plays an important role during vermicomposting of organic wastes, as the type and proportion of bulky material in vermireactors not only influences the mineralization rate, but at the same time also alters the earthworm biomass production rate (Suthar, 2009). An earlier study, like Suthar (2008), has revealed that mixing of bulky material in some noxious wastes minimizes the concentration of toxic substances in vermireactors and consequently speeds the decomposition process. The importance of bulking material in vermicomposting of waste is as follows:

(1) It makes the waste more acceptable for earthworms,

(2) Lowers the concentration of some unfavorable chemicals, e.g., metals, grease, lignin, polyphenolic substances and cellulose in feedstock,

(3) Sets the pH within the acceptable limit for earthworms,

(4) May enhance the nutritive value of waste and thereby accelerate the decomposition through enzymes production by earthworms and associated micro-flora,

(5) Enhances the quality of ready product, i.e., vermicompost by adding some important nutrients; and,

(6) Changes the microclimatic conditions of the decomposing waste by promoting microbial colonization in feedstock, although microbes are an important part of the earthworm diet.