African Journal of Agricultural Research Vol. 5(13), pp. 1553-1571, 4 July, 2010
Available online at http://www.academicjournals.org/AJAR
DOI: 10.5897/AJAR09.016
ISSN 1991-637X ©2010 Academic Journals

Full Length Research Paper

Oil palm composted biomass: A review of the preparation, utilization, handling and storage

P. O. Oviasogie*, N. O. Aisueni and G. E. Brown

Chemistry Division, Nigerian Institute for Oil Palm Research (NIFOR), P. M. B. 1030, Benin City, Edo State, Nigeria.

Accepted 19 March, 2010

The preparation, utilization, handling and storage of oil palm composted biomass were reviewed in the present study. The preparation of the compost was found generally to be catalyzed by microorganisms aiding the decomposition and stabilization of organic material. The heat produced during the microbial build up helps to produce a final product that is stable, free of pathogens and viable plant seeds, and can be beneficially applied to the land. Compost has numerous agronomic and horticultural uses. It can be used as a soil amendment, fertilizer supplement, top dressing for pastures and hay crops, mulch for homes and gardens, and a potting mix component. The use of compost aids in increasing the water and nutrient retention of the soil, provides a porous medium for roots to grow in, increases the organic matter and decreases the bulk density or penetration resistance of soils as well as controlling disease pathogens. Composting process tends to concentrate many chemical constituents and alter physical characteristics thus, the testing for specific parameters is important before handling and use which can be compared with the typical ranges of test parameters in quality compost. This review revealed that composting is receiving increased attention as an alternative manure management practice. Composting enhances the usefulness of organic by-products as fertilizers, privately and commercially.

Key words: Oil palm composted biomass, preparation, utilization, handling, storage.

INTRODUCTION

Composting is a viable means of transforming various organic wastes into products that can be used safely and beneficially as biofertilizers and soil conditioners. It can resolve a number of problems associated with the use of raw and unstable organic wastes as soil amendments such as malodors, human pathogens, and undesirable chemical and physical properties EEMS (2009). During the composting process, organic wastes and plant nutrients are mineralized into plant-available forms, pathogens are destroyed, disease infestation is suppressed by pressed partial sterilization, pollutants are detoxified and malodors are abated (Parr and Hornick, 1992; Chica et al., 2003). Composting is a microbiological process that depends on the growth and activity of mixed populations of bacteria, actinomycetes, and fungi that are indigenous to the wastes being composted. It can be done by either aerobic or anaerobic methods. However, the aerobic method is generally preferred, since most of the decomposers are aerobic. Furthermore the aerobic method proceeds more rapidly and provides greater pathogen reduction because higher temperatures are attained.

During composting, microorganisms use the organic matter as carbon and energy sources, producing heat, carbon dioxide, water vapor, and humus as a result of

*Corresponding author. E-mail: philipoviasogie5@yahoo.com. Tel: +2348063734237.

their furious growth and activity. Humus makes up approximately 60 percent of finished compost. Mature compost is an excellent organic fertilizer and soil amendment (Yusri et al., 1995). When applied to and mixed into the soil, it can promote good soil structure, improve water- and nutrient-holding capacity, and help to control erosion. A management plan is needed to maintain proper temperature, oxygen and moisture for the organisms (Yusri et al., 1995). Testing temperature, moisture content, and oxygen levels can help in making decisions on composting activities, such as turning, aerating, or adding moisture. These tests can be performed quite simply on site giving quick feedback – from minutes for temperature or oxygen to overnight for moisture content (Thompson et al., 2002). One of the agricultural wastes commonly generated in Nigeria is the Oil Palm Bunch Refuse. This is because the country before 1965 was the foremost leader in World Oil Palm production and export before it relinquished it to Malaysia and Indonesia. Nigeria is still the world's third largest producer and clearly the largest producer in Africa. The oil palm waste, which has been estimated from this industry at about seven million metric tones annually, is yet to be harnessed for the production of organic manures and agricultural development generally. The estimate was based on the total oil palm hectare of the country, its yield potential of fresh fruit bunches (f.f.b) and percentage fruit components in terms of oil, kernel and bunch refuse (Aisueni, 2003). The recycling of agricultural wastes and by-products by composting is an important part of sustainable agriculture. Empty Fruit Bunches (EFB) is a suitable raw material for recycling because it is produced in large quantities in localized areas.

In the past, it was often used as fuel to generate steam at the mills (Ma et al., 1993). The ash, with a potassium content of about 30%, (Lim, 2000) was used as fertilizer. Burning is now prohibited by regulations to prevent air pollution. The EFB is now used mainly as mulch (Hamdan et al., 1998). Placed around young palms, EFB helps to control weeds, prevent erosion and maintain soil moisture. However, due to labor shortages in oil palm plantations, the transportation and distribution of EFB in the field is getting more expensive. There is a growing interest in composting EFB in order to add value, and also to reduce the volume to make application easier (Yusri et al., 1995; Thambirajah et al., 1995; Damanhuri, 1998). This paper discusses major aspects involved in EFB compost. These are related to the physical characteristics of the raw materials.

COMPOST MICROORGANISMS

Sources

The composting microorganisms are found throughout the natural environment. They are present in compost feedstock as well as in the water, air, soil, and machinery. The feedstock and compost are exposed to microbial decomposition during processing (Haug, 1993). The microbiological components of compost consist of bacteria and fungi. The majority of microorganisms responsible for the formation of compost are aerobes in that they require or work best in the presence of oxygen. Many difficulties associated with composting may be traced to insufficient oxygen levels to support the decomposition of compost feedstock. Compost microbes also require a moist environment because they live in the water films surrounding composting organic matter particles. 50 to 60% moisture content is optimal (Bates et al., 1997).

Fungi

Fungi form their individual cells into long filaments called hyphae. Fungal hyphae are larger than actinomycetes and may be more easily seen with the naked eye. They penetrate throughout the composting material, decomposing both chemically and mechanically the more recalcitrant organic matter fraction such as lignin and cellulose. Fungal hyphae physically stabilize the compost into small aggregates, providing the compost with improved aeration and drainage (Nancy and Elaina, 1996). Fungi number between 0.01 and 1 million propagules per gram of soil. About 70,000 different species of fungi have been described worldwide, but an estimated 1 million additional species remain undiscovered and undescribed. Ecologically, fungi play a vital role in breakdown of dead plant materials (EPA, 1999).

Bacteria

The most numerous biological component of compost is the bacteria (EPA, 1999). Although they often can exceed 1 billion microorganisms per gram of soil, bacteria (with the exception of actinomycetes) do not contribute as much to the overall microbiological mass as fungi because of their relatively small size. Although bacteria (with the exception of actinomycetes) exist as individuals and do not form filaments, they also contribute to the stabilization of aggregates through the excretion of organic compounds that bind adjacent organic matter and soil particles together. Bacteria are typically associated with the consumption of easily degraded organic matter (NRAES, 1999). They are the dominant population throughout the entire composting process, whereas the actinomycetes and fungi typically proliferate in the later stages (NRAES, 1999).

Actinomycetes

While actinomycetes are visually similar to fungi in that they have networks of individual cells that form filaments or strands, they are actually a type of bacteria. These filaments allow for a colony of actinomycetes to spread throughout a compost pile, where they are typically associated with the degradation of the more recalcitrant compounds (Yusri et al., 1995). Actinomycetes number between 0.1 and 10 million propagules per gram of soil. Their filaments contribute to the formation of the stable organic aggregates typical of finished compost. Actinomycetes are tolerant of lower moisture conditions than other bacteria and are responsible for the release of geosmin, a chemical associated with the typically musty, earthy smell of compost (Bates et al., 1997).

COMPOST PREPARATION

During different composting stages, temperatures and nutrient availabilities vary and affect the kinds and numbers of microorganisms that develop. The initial temperature of the pile is at approximately the ambient temperature. The composting material warms through the mesophilic temperature range (10 - 40°C) (exothermic process) as the microorganisms (Mesophiles) become more active during which sugars and other simple carbohydrates are rapidly metabolized. The mesophilic stage continues for about a week. Soon, microbial activity raises the temperature of the pile to thermophilic temperatures (41 - 76°C) (Yusri et al., 1995).

This is considered the most productive stage of composting and lasts for about two weeks. Such a drastic increase in temperature is accompanied by the decomposition of cellulose and other resistant materials by the thermopiles. It is important that the material be thoroughly mixed and kept aerated during this stage. Eventually, readily available substrates within the feedstock are exhausted, temperatures gradually return to the mesophilic range, and curing begins. Mesophillic organisms are usually fungal-dominated and useful to restore bacteria dominated soils. The following section expands on the microbiology of each stage (Rynk and Richard, 2001).

Initial stage

The process of transporting and manipulating the feedstock for composting exposes the organic matter to additional sources of microorganisms, all of which may contribute toward initiating the composting process. Initially, mesophiles predominate and proceed to decompose the readily degradable sugars, proteins, starches, and fats typically found in undigested feed stocks.

The availability of easily usable organic substances enables the proliferation of the fastest-growing microorganisms (Donahue et al., 1990). Mesophilic bacteria, therefore, dominate initial decomposition. These bacteria release heat from the breakdown of large amounts of easily degraded organic matter. This heat begins to raise the temperature within the pile due to the high insulating capacity of a properly sized compost pile. Within just hours the temperature of the compost pile can rise above the 41°C thermophilic threshold (Francou et al., 2005).

Active stage

As the compost reaches higher temperatures, thermophiles begin to dominate the bacterial community. The active stage is typically the stage where most of the organic matter is converted into carbon dioxide and humus, and the microorganism population grows. The thermophilic population continues generating more heat by decomposing the remaining organic matter. Due to limitations with isolation techniques (Insam et al., 2004), laboratory studies have only been able to isolate a few genera of bacteria from the thermophilic stage (*Bacillus*, *Clostridium*, and *Thermus*), but many microorganisms remain to be discovered and described. In a properly ventilated composting pile, the temperature will be maintained between approximately 55 and 68°C. Fortunately, pathogens such as human viruses and infectious bacteria are typically unable to persist in such a hostile environment. The higher temperatures will ensure rapid organic matter processing while simultaneously providing optimal conditions for the destruction of human and plant pathogens as well as weed seeds (Brady and Weil, 2002).

Because the composting pile is cooler on its outer surface, periodic mixing of the outer layer into the pile is essential for maximum pathogen and seed kill. Mixing or turning the pile also helps to ventilate it by increasing the size and number of air pores. This is important because in an unventilated compost pile, the temperatures can exceed 71°C, effectively stopping all microbial activity. The air pores also serve as passages for oxygen to enter the pile. Microbes require oxygen to efficiently break down organic matter (Rynk and Richard 2001).

Over heating

If a pile does over heat, surpassing approximately 77°C, most microbes will be destroyed and microbial activity will virtually cease. Spore-forming microorganisms are able to survive as spores at this high temperature. The spores germinate when the composting pile returns to a more favorable temperature. These spores are thick-walled structures that are formed by the microorganism under stress such as heat, cold, drought, and low nutrient conditions (Insam et al., 2004).

After overheating, the composting pile will cool to a mesophilic state, requiring the activity of mesophilic microorganisms to return the pile to thermophilic conditions. If the composting pile is low in readily utilizable organic substrates, the pile may not be able to support the microbial activity needed to return to thermophilic conditions.

In such a case, it may be necessary to supplement the composting pile with additional feedstock to ensure maximal degradation and pathogen removal (Rynk and Richard, 2001). An overheated composting pile may return to thermophilic temperatures through the germination and activity of spore-forming microorganisms, and through the infiltration of microorganisms from the outer surface of the composting pile where the temperature was less extreme (Insam et al., 2004).

Curing stage

The final stage of composting is the curing phase when immature compost is converted into mature one (Ingham, 1999). A properly functioning composting pile will eventually deplete itself of a majority of the easily degradable organic substrates leaving some cellulose, but mainly lignin and humic materials. Bacteria are generally considered less adept at metabolizing these remaining compounds. Consequently, the bacterial population will decline in numbers as compared to fungi and actinomycetes. Because less heat is generated at this point, the temperature of the composting pile will slowly fall to mesophilic temperatures. With the return of mesophilic conditions, the final curing stage of composting begins (On-Farm Composting Handbook, 1992).

During the curing stage, the fungi and actinomycete populations predominate (Ingham, 1999), while the bacterial population may decline somewhat. Fungi and actinomycetes proliferate on the remaining less degradable organic matter such as chitin, cellulose and lignin. These compounds are more persistent because they are insoluble in water and, due to their size and chemical complexity cannot pass into the bacterial cell. Thus, degradation of these compounds requires the use of extracellular enzymes (EPA, 1998). Once the complex organic compounds are broken down into smaller and more soluble forms, they can enter the cell and become food and energy for the microorganism. Microbes able to produce extracellular enzymes suitable for breaking down recalcitrant materials will have a selective advantage at this point in the composting process. A novel feature of many of the extracellular enzymes common in fungi is that they are capable of breaking down a wide range of compounds that would otherwise require several specific enzymes, a feature not commonly found in a single microorganism. Fungi, though they grow and reproduce more slowly than bacteria when food is readily available, are well suited for exploiting an environment rich in complex recalcitrant organic compounds like those found in the compost during the curing stage (Barker, 1997).

The curing process can vary in duration; a longer curing period provides more assurance that the compost is free of pathogens and phytotoxins. If the compost is incompletely cured (that is, not stable), it maintains a higher microbial activity, leading to increased oxygen consumption. When unstable compost is applied in the field, it can thereby decrease the supply of oxygen available to plant roots (Mayer et al., 1998). In addition, immature compost can contain higher levels of soluble organic matter (that is, organic acids), which can lead to toxicity problems for certain horticultural applications, such as seed germination (Tester, 1990). As the curing stage continues, there is a gradual increase in the humus fraction. Humus is a complex class of chemicals that result from the incomplete degradation of organic matter. Humus is among the most resistant compounds to degradation in nature. It is also one of the major mechanisms for the retention of nutrients (e.g., nitrogen, phosphorus) and micronutrients (e.g., copper, zinc, iron, manganese, calcium) in the soil. Because humic compounds retain micronutrients and water so well, they are often the site for the highest biological activity, including microorganism, protozoan, invertebrates (e.g., worms, springtails) and plants (Barker, 1997). At the completion of this process, the plant or other organic parts (leaves, roots, etc.) are no longer identifiable in the compost. The humification of organic material is characterized by an increase in concentration of humic acids from approximately 4 to 12 percent, and a decrease in the C/N ratio from thirty in the original material to about ten in the final product. Figure 1 shows a typical material flow for the conventional composting process.

Table 1 shows the acceptable ranges of the typical factors that affects composting process. At these ranges, mature and treated compost is expected to be achieved at the end of the composting process. Table 2 above, gives a basic approach to different requirements in composting methods, dependent on the type and pattern of the windrow used for the compost preparations. Factors considered include labour, siting, bulking agent, active period, curing, odour, e.t.c.

COMPOSTING EMPTY FRUIT BUNCHES OF OIL PALM

An average oil palm mill can handle about 100 metric tonnes (mt) of fresh fruit bunches daily. At the mills where oil extraction takes place, solid residues and liquid wastes are generated. The solid residues, mainly EFB, are more than 20% of the fresh fruit weight (Ma et al., 1993; Kamarudin et al., 1997). More than 500 kg (around 0.5 m^3) of liquid wastes, mainly in the form of palm oil mill effluent (POME), are discharged during the processing of 1.0 mt of fresh fruit bunches (Ma et al., 1996). Thus, we would expect to get more than 20 mt of EFB and more than 50 m^3 of POME from a mill after processing 100 mt of fresh fruit bunches.

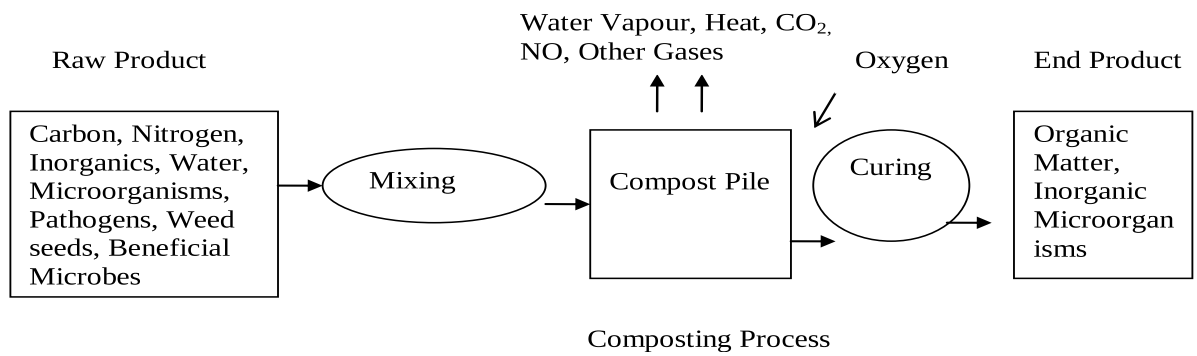

Figure 1. Material flow for the conventional composting process.
(Source: Ministry of Agriculture and Food. London, B.C Agricultural Composting Handbook, 1998).

Table 1. Factors affecting the composting process and acceptable ranges.

Factor	Acceptable range
Temperature	54 - 60°C
Carbon to Nitrogen ratio (C:N)	25:1 - 30:1
Aeration, percent oxygen	> 5%
Moisture Content	50 - 60%
Porosity	30 - 36
pH	6.5 - 7.5

Source: Alexander 1994.

The main contributors of biomass in the palm oil industry include;

– Empty fruit bunches (EFB)
– Palm oil mill effluent (POME)
– Mesocarp fiber
– Palm kernel shells
- Palm kernel cake (residue)

EFB is composed of 45 - 50% cellulose and about equal amounts (25 - 35%) of hemicellulose and lignin (Deraman, 1993). It is fibrous, and the fibers stick together to form vascular bundles. A common method used to reduce the size of EFB before composting is hammer milling. The C/N ratio of fresh EFB is about 60 (Hamdan et al., 1998). Other materials are often added, particularly chicken manure and POME to narrow the C/N ratio. However, POME has a high nutrient content (Zakaria et al., 1994), and large oil palm plantations prefer to use it directly as fertilizer. The POME is first treated to reduce the organic load (Ma et al., 1993). The sediments left after treatment, which have a higher nutrient value than the slurry (Zakaria et al., 1994), are either recycled to the field or sold to the public.

Composting of EFB has been extended to farmers by the Department of Agriculture of Malaysia (Damanhuri, 1998). The initial method the Department adopted was to mix the EFB with 20% chicken manure, heap it in 3 x 3 x 0.7 m boxes, and cover it with plastic. It took 11 to 12 months to mature. In 1995, the method was modified by first exposing big piles of EFB in an open area for two months. The EFB was then mixed with 20% chicken manure and heaped in sheds measuring 12 x 36 x 3 m. The heap was mixed at regular monthly intervals. The time taken to reach maturity was about four months. Maturity was determined when the temperature of the heap stabilized at 30°C, and the pH reading was 4.5 - 6.0. Mixing was carried out with a tractor equipped with a backhoe. It was reported by Damanhuri, 1998 that about 15 m^3 of compost could be turned in one hour. Shredding of the compost was carried out at the end of the composting period. The shredded material was left for one to two weeks prior to packing. The final product contained a reasonable amount of nitrogen (3.3%), phosphate (0.05%), potassium (0.2%), calcium (1.0%) and magnesium (0.2%). A large EFB composting installation is currently being operated by a commercial company in Malaysia. The daily out put is about 10 mt.

Operations are semi-mechanized. The EFB is passed through a hammer mill, collected by tractors and piled in windrows. Chicken manure (around 15 - 20%) is added, and mixed in by a mechanical implement which straddles and moves along the windrow. The whole process is carried out in the open. Leachates or run-off after rain are

Table 2. Basic composting methods.

	Bin	Passive windrow	Active windrow	Aerated static windrow	In-vessel channel
General	Low technology, medium quality.	Low technology, quality problems.	Active systems most common on farms.	Effective for farm and municipal use.	Large-scale systems for commercial applications.
Labour	Medium labour required.	Low labour required.	Increases with aeration frequency and poor planning.	System design and planning important. Monitoring needed.	Requires consistent level of management/product flow to be cost efficient.
Site	Limited land but requires a composting structure.	Requires large land areas.	Can require large land areas.	Less land required given faster rates and effective pile volumes.	Very limited land due to rapid rates and continuous operations.
Bulking agent	Flexible.	Less flexible, must be porous.	Flexible.	Less flexible, must be porous.	Flexible.
Active period	Range: 2 – 6 months	Range: 6 – 24 months	Range: 21 - 40 days	Range: 21 - 40 days	Range: 21 – 35 days
Curing	30+ days	Not applicable.	30+ days	30+ days	30+ days
Size: Height	Dependent on bin design.	1 – 4 m	1 - 2.8 m	3 - 4.5 m	Dependent on bay design.
Size: Width	Variable.	3 – 7 m	3 - 6 m	Variable.	Variable.
Size: Length	Variable.	Variable.	Variable.	Variable.	Variable.
Aeration system	Natural convection and mechanical turning.	Natural convection only.	Mechanical turning and natural convection.	Forced positive/negative airflow through pile.	Extensive mechanical turning and aeration.
Process control	Initial mix or layering and one turning.	Initial mix only.	Initial mix and turning.	Initial mix, aeration, temperature and/or time control.	Initial mix, aeration, temperature and/or time control, and turning.
Odour factors	Odour can occur, but generally during turning.	Odour from the windrow will occur. The larger the windrow the greater the odours.	From surface area of windrow. Turning can create odours during initial weeks.	Odour can occur, but controls can be used, such as pile insulation and filters on air systems.	Odour can occur. Often due to equipment failure or system design limitations.

(Source: Ministry of agriculture and food. London, B.C Agricultural Composting Handbook, 1998).

collected in specially constructed drains to prevent the loss of added nutrients. The water from these drains is used to moisten the compost. Mixing is carried out regularly, to maintain an even distribution of moisture and to prevent the build-up of heat. The process takes a total of 45 to 60 days. The sieved compost is dark brown, and has an earthy smell (Snow, 1999).

The decomposition of EFB in oil palm plantations was studied by Hamdan et al. (1998). The EFB was spread in the field as mulch on top of nylon net, at a rate of 30, 60 and 90 mt/ha/year. At each EFB application rate, spots were selected for nitrogen supplementation to meet a C/N ratio of 15, 30 and 60 (control). Decomposition was estimated by the weight of EFB remaining in the nylon net. The EFB was found to be completely decomposed after 10 months of application. It appeared that the more detailed studies of decomposition of EFB in the field were independent of N supplementation (Table 3). More detailed studies of EFB decomposition have also been carried out, using microorganisms.

Different organic nitrogen sources, such as the manure of goats, cattle and chickens, have also been evaluated as nitrogen additives for the composting of EFB (Thambirajah et al., 1995). Adding 25 kg of manure per 90 kg shredded EFB reduced the CN ratio. EFB compost with goat manure, cattle manure and chicken manure had a C/N ratio of 14:1, 18:1 and 12:1, respectively, after 60 days of composting, while the control without manure had a C/N ratio of 24:1. Research into the composting of EFB is intended to develop a commercially viable compost production system. Of utmost importance is the production

Table 3. Decomposition of Efb in the field.

Treatment		Decomposition rate (%)				
		Months after application				
EFB application Mt/ha/year	C/N ratio	2	4	6	8	10
30	30	42.84	64.40	82.14	98.17	100
30	60	17.82	53.40	71.16	96.93	100
30	15	32.71	36.85	68.17	98.90	100
60	60	36.19	68.14	85.81	98.34	100
60	30	28.16	49.54	89.87	99.59	100
60	15	26.30	52.54	78.90	99.15	100
90	60	26.47	56.61	85.00	96.27	100
90	30	38.26	63.02	87.36	97.96	100
90	15	25.27	66.94	83.88	97.97	100

Source: Adapted from Hamdan et al. (1998).

Table 4. Chemical characteristics of materials for compost.

Material	pH	Oil and fat	BOD	COD	Total carbon (%)	TS	SS	TVS	Nitrate	Total nitrogen (%)	Phosphorus (%)
Empty fruit bunches	ND	ND	ND	ND	43.7	ND	ND	ND	ND	0.52	0.05
Fermentation wastes	3.54	ND	86,100	154,046	ND	ND	ND	ND	3.33	4.75	0.64
POME	4.7	4,000	25,000	50,000	NA	40,000	18,000	34,000	35	750	180

Material	Potassium (%)	Manganese (%)	Sulpur (%)	Calcium (%)	Boron (%)	Iron (%)	Magnesium (%)	Copper (%)	Zinc (%)	Reference
Empty fruit bunches	1.34	0.07	0.07	0.19	4	649	20	13	21	Suhaimi and Ong, 2001
Fermentation wastes	0.37	0.p3	4.2	0.08	ND	ND	0.0002	ND	ND	Suhaimi and Ong, 2001
POME	2,270	615	NA	439	7.6	46.5	2	0.89	2.3	Ngan et al., 1996

Except pH, unless indicated the figures are in ppm.
ND = Not determined, NA = Not available.

of high-quality compost in a short period of time. Chicken manure, POME and liquid fermentation wastes from the food processing industry, have all been investigated as additives. Both POME and liquid fermentation wastes are generated in large quantities, and there is considerable interest in recycling them. The chemical characteristics of these materials and EFB are shown in Table 4.

A concluded study by Suhaimi and Ong (2001) in Malaysia was on composting of EFB in two methods (Open and Closed system). In the closed system, a semi-permeable membrane was used to cover the windrow pile. The height of the pile was 1.5 m. The closed composting process was carried out with aeration at a rate of about 250 mt/day/m^3. The air was supplied by an electric pump through perforated tubes laid at the bottom of the pile. Eighty metric tonnes of

EFB were mixed with POME and chicken manure. In the open system, the pile was not covered but protected from rainfall. One metric tone of EFB was used, and liquid fermentation wastes and chicken manure were added. Regular turning was carried out manually with the aid of a tractor equipped with a front loader. Both lots of composting material had an initial C/N ratio of about 30, and a moisture content of about 65%. Water was added to maintain the required moisture level. Temperatures were monitored at 10 and 100 cm from the surface of the compost heaps.

The temperature profile (Figure 2) reflects the importance of mixing. The initial temperature was quite high. The lag phase was brief, indicating composting started early on. This early high temperature was the same at 10 and 100 cm. Marked differences appeared as composting progressed. In the closed system, the temperature deep in the pile was higher than near the surface, except after turning. In the open system, where regular mixing was carried out, the temperature (Figure 3) was evenly distributed during the course of the composting period. The decline in temperature occurred in pace with decomposition. The gradual decline in temperature corresponded with the decline in the C/N ratio. However, composting was not completed, as the final temperature was more than 35°C. Changes in C/N ratio and chemical composition were monitored by sampling as composting progressed. It was observed that EFB were used differently in the open and closed systems. For the closed system, the EFB were reduced in size by a hammer mill. For the open system, they were cut into pieces. The conventional and readily available mixing technique was found to be inefficient. The distribution of the other inputs was uneven resulting in a high initial C/N ratio (41, open; 56, closed). The distribution of moisture during composting was uneven in the closed system. This resulted in uneven biological activity. The composting process progressed at a reasonable rate, but faster for the open system. A C/N ratio of about 16 was achieved in about 50 days (open) and 85 days (closed) (Figure 4). The resulting compost mixture was not homogeneous, and as a result the C/N ratio value was higher than expected (Table 5 and 6). It was as high as 52 in large compost heap using 80 mt of EFB. When a smaller amount (1 mt) of EFB was used, mixing was found to be more effective and the C/N ratio was lower, at 41. A fungi inoculant was found to accelerate the composting process, making it possible to produce mature compost in six weeks. Fresh compost was inoculated, not by isolating the spores, but by recycling around 10% of the mature compost into fresh composting mixture.

Composting EFB in Malaysia

Malaysia is the world's largest oil palm producer, with more than three million hectares of oil palm plantation. The oil palm industry generates around 90 million each year of renewable biomass. About 8 million tons of this is the empty fruit bunches (EFB) left after the oil is extracted. In the past, these were often burnt as fuel by oil mill extraction mills. However, new environmental regulations now forbid this practice because of air pollution. Organic compost was successfully produced using POME sludge, shredded EFB, MSW and domestic sewage sludge. Good properties such as pH 6 - 8, C/N 20 and comply with USEPA standards. Performance was comparable with commercial composts Suitable for vegetables and ornamental plants (Anon, 2002).

MATERIALS AND METHODS

Raw materials

Basic raw material

The fruit bunches are harvested and run through a steam process which loosen the fruits. The fruits are then dislodged by vigorous shaking; leaving empty fruit bunches (EFB) (Figure 5). By using EFB which contains high organic content and natural occurring nutrients, the raw material is 100% agricultural. Its abundance in Malaysia, guarantees consistent supply all the time (Figure 6).

This is a by-product of the Palm Oil extraction process. Steam and hot water are used to sterilize and clean the crude oil, the resultant mixture of this with the residue from the oil becomes POME. POME contains substantially high contents of soil nutrient (Figure 7).

The process

Empty fruit bunches or EFB, broken down into strips of fiber by using a hammermill shredder (Figure 8). With the EFB being broken down into strips of fiber, the decomposition process of EFB is much faster (Figure 9). The shredded EFB is mixed with POME (Palm Oil Mill Effluent) which is rich in nitrogen and stacked up into rows of compost piles called windrows. The picture shows two rows, one before mixing and the other after (Figure 10a). The compost turner plays a pivotal role in ensuring that the process remains aerobic. Regular turning maintains the right amount of oxygen and moisture content (Figure 10b). The compost site which is spread over a 20-acre site is fully mechanized and can produce up to 1,500 metric tons per month (Figure 11).

Monitoring

Monitoring of temperature, moisture, oxygen and carbon dioxide content to ensure weed seeds and harmful pathogens are destroyed in the process (Figure 12).

The product

Composting cycle was completed in about 8 - 10 weeks. This rich soil amendment can be used to improve any type of problem soil (Figure 13).

Packing

The finished compost was packed into 25 kg bags (Figure 14).

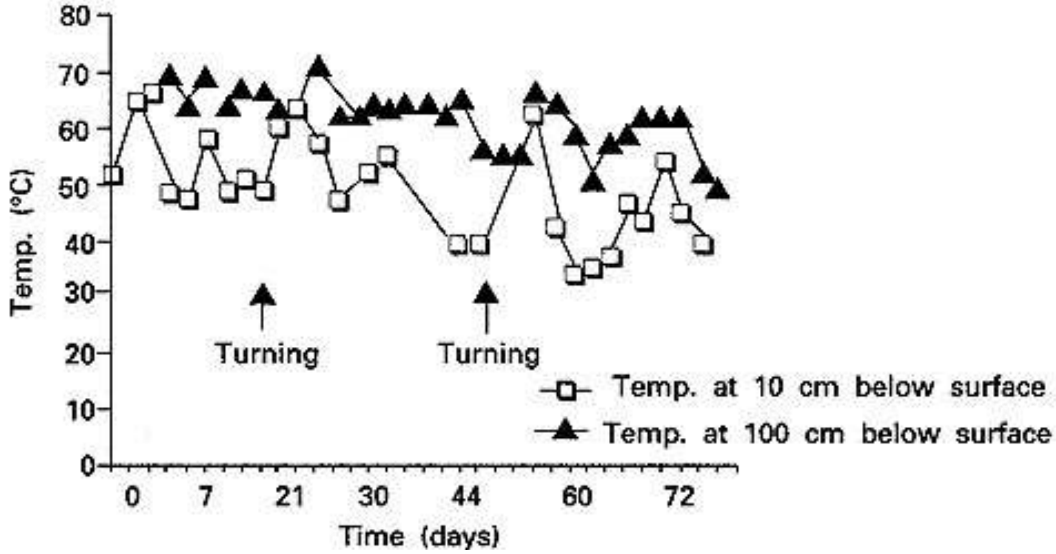

Figure 2. Temperature variations in the closed composting system.
Suhaimi and Ong (2001).

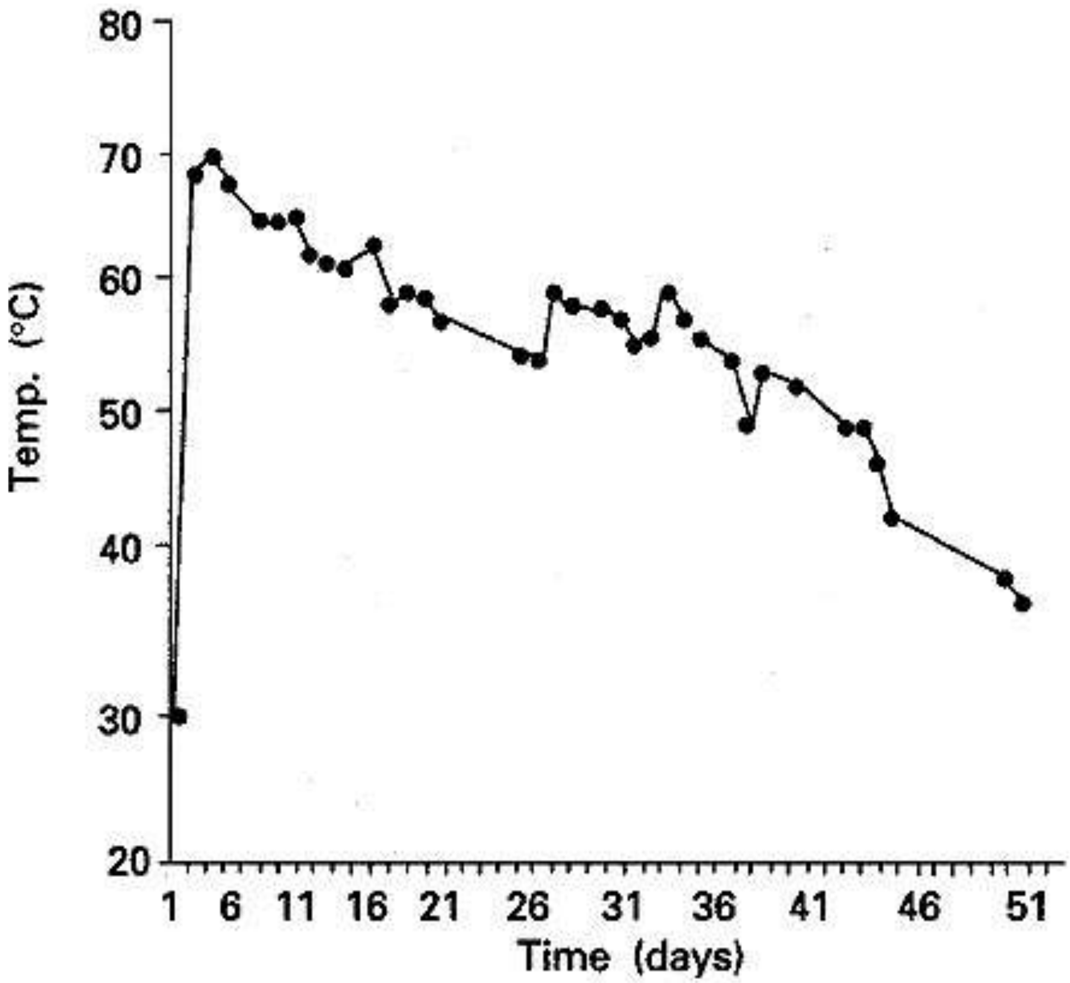

Figure 3. Temperature profile of the open composting system.
(Suhaimi and Ong, 2001).

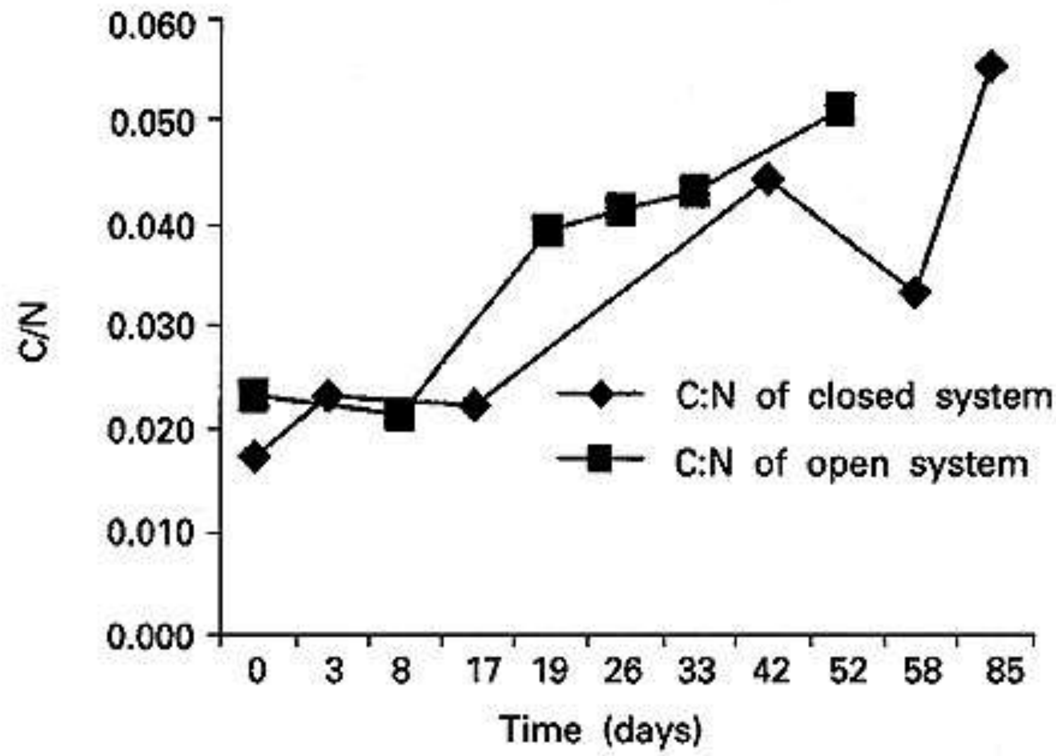

Figure 4. Nitrogen stability attributes.
(Suhaimi and Ong, 2001).

Table 5. Changes in the chemical composition of the compost in the closed composting system.

Time (h)	Nutrient content (%)							Nutrient content (ppm)					C/N
	C	N	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B	
0	43.11	0.76	0.21	2.60	0.58	0.20		97.0	7,256	30.0	68.0	21.0	56.7
3	45.67	1.05	0.34	2.71	1.10	0.27	0.17	131.0	8,136	38.0	105.0	13.0	43.5
17	44.21	0.98	0.32	2.95	0.98	0.26	0.22	168.0	5,694	36.0	149.0	17.5	27.5
42	39.00	1.92	0.55	2.97	1.80	0.45	0.22	168.0	5,694	36.0	149.0	17.5	27.5
58	38.90	1.46	0.34	2.14	1.19	0.34		117.0	3,244	26.0	105.0	11.0	26.6
85	39.70	2.43	0.65	2.56	2.21	0.57	0.25	214.0	6,414	37.0	177.0	17.0	16.3

(Suhaimi and Ong, 2001).

Table 6. Changes in the chemical composition of the compost in the closed composting system.

Time (h)	Nutrient content (% DM)								Nutrient content (ppm)					C/N
	C	N	NH4+N	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B	
0	44.86	1.09	0.23	0.10	0.69	0.33	0.07	0.66	31.3	1673	20.9	135.4	5.9	41.2
8	42.18	0.98	0.02	0.25	0.84	0.61	0.10	0.45	44.8	2525	23.9	57.1	2.8	43.9
19	42.43	1.80	0.02	0.22	1.51	0.72	0.16	0.79	55.1	1699	19.6	187.0	10.6	23.6
26	39.12	1.87	0.02	0.25	0.98	1.01	0.15	0.55	67.7	2455	21.8	78.8	11.5	20.9
33	37.09	1.96	0.02	0.30	1.03		0.18	0.63	77.5	2644	26.5	87.9	12.1	18.9
52	37.08	2.34		0.30	0.96	1.15	0.17	0.54	76.3	2891	28.3	93.0	13.7	15.9

(Suhaimi and Ong, 2001).

Figure 5. Fruit bunches from oil palm tree.

Figure 6. Empty fruit bunches.

Figure 7. Palm oil mill effluent from crude palm oil (CPO).

Figure 8. Shredding of empty fruit bunches.

Figure 9. Shredded EFB.

Figure 10a. Mixing of EFB with POME and building piles of windrow.

Figure 10b. Turning of windrow piles with turner.

Figure 11. Rows and rows of windrow at various stages of decomposition.

Figure 12. Daily monitoring.

Figure 13. Bio-organic compost.

Figure 14. Packing machine with three discharge chute.

Application

Flora mass can be applied to barren or infertile soils to convert them to productive and viable agricultural land. It can be used as basal dressing to amend soils or it can be used as a top dressing fertilizer to provide nutrient elements like nitrogen, phosphorous, potassium, etc (Figure 15).

COMPOST UTILIZATION

Compost has numerous agronomic and horticultural uses. It can be used as a soil amendment, fertilizer

Figure 15. Using flora mass.

supplement, top dressing for pastures and hay crops, mulch for homes and gardens, and a potting mix component. In these examples, the compost increases the water and nutrient retention of the soil, provides a porous medium for roots to grow in, increases the organic matter and decreases the bulk density or penetration resistance (Anon, 2002). Highlighted below are the major areas of compost utilization;

Compost introduces beneficial microorganisms

When incorporated into soil, compost introduces a wealth of beneficial microorganisms. Plant and human pathogens are destroyed during the composting process. The remaining beneficial microbes assist with a number of functions that assist in soil and plant health (Barker, 1997).

Nutrient cycling

To be available to plants, nitrogen must be in an inorganic form, such as nitrate (NO_3^-) or ammonium (NH_4^+). Plants are not capable of converting organic nitrogen to these inorganic forms. Fortunately, microorganisms commonly found in soil and compost convert organic nitrogen into inorganic nitrogen, a process called mineralization. Plants may then take up the nutrients released by these. Soils that have been exposed to harsh agricultural pesticides, such as methyl bromide, may have reduced populations of these beneficial microorganisms. Compost may help to re-inoculate these soils with nutrient-cycling microbes. It is important to note that inadequately cured, unstable compost may immobilize nitrogen in soil (Barker, 1997).

Disease suppression

Composts contain an astonishing variety of microbes, many of which may be beneficial in controlling pathogens. Beneficial microbes help to control plant pathogens through either specific or general suppression. General suppression occurs when a beneficial microbe fills an ecological niche that would otherwise be exploited by a pathogen. For example, a beneficial organism may outcompete a pathogen for energy, nutrients, or "living space," thereby decreasing the survival of the pathogen.

Specific suppression occurs when a beneficial organism secretes chemicals toxic to a pathogen or when it preys upon the pathogen for food. Many plant pathogens contain cellulose (the principal component of paper) or chitin (commonly found in insects, and fungi), and all contain sugar-polymers (commonly found in all life). Certain compost microorganisms, such as *Gliocladium*, *Pseudomonas*, *Trichoderma,* and *Streptomycetes,* produce enzymes capable of breaking these compounds down, killing the pathogens in the process (Bezdicek et al., 2000). Exposure to heat during the thermophilic stage of composting is often responsible for killing plant and human pathogenic microorganisms. This heat also kills those beneficial microorganisms that cannot tolerate the high temperature. Thus for compost to serve as a means for minimizing plant pathogens in the field, it must be re-colonized by beneficial microorganisms. Commercial compost producers in California do not routinely inoculate their compost. Analysis, when performed, commonly shows that this re-inoculation occurs naturally. However, some studies suggest that controlled inoculation of compost with known biocontrol agents (fungi and bacteria) is necessary for consistent levels of pathogen suppression in the field after application.

Degradation of pollutants

Mature compost has been shown to be an effective tool for reducing organic pollutants in contaminated soils and water. Compost bioremediation has proven effective in degrading or altering many types of contaminants, including chlorinated and nonchlorinated hydrocarbons, solvents, pesticides, and petroleum products. The microorganisms in the compost break down the contaminants into components that pose less of an environmental hazard.

Compost provides a source of organic material

Soil organic matter can come from a variety of sources, including crop or plant residues, cover crops, and compost. Compost consists primarily of organic matter, which serves a variety of vital functions in the soil (Bates et al., 1997; Francis and Xiying, 2007):

Provides food for microorganisms

Bacteria and fungi that release nutrients from soil use

Table 7. Typical ranges of test parameters in quality compost.

Test parameter	Range
pH	6.8 - 7.3
Soluble Salts	0.35 - 0.64 dS/m (mmhos/cm) (1:5 v/v method)
Nitrogen	1.0 - 2.0%
Phosphorus	0.6 - 0.9%
Potassium	0.2 - 0.5%
Moisture Content	45 - 50%
Organic Matter	35 - 45%
Particle Size	passes 3/8" screen
Bulk Density	900 - 1,000 lbs/yd^3

Snow, 1999.

organic matter as their food or source of energy. Thus, compost provides a source of both microorganisms and their fuel. Compost also provides an excellent habitat for microorganisms.

Holds nutrients and water

In addition to providing a source of nutrients, organic material can hold onto many nutrients through its cat ion exchange capacity. Because compost molecules are negatively charged, they attract and hold onto positively charged ions, such as calcium, potassium, ammonium, and magnesium.

Forms aggregates and increases porosity

Organic matter increases the aggregation of soil that results in a crumb-like structure. Changes in porosity can alter water retention properties and the water infiltration rate. Consequently, consistent compost use may improve irrigation efficiency.

COMPOST HANDLING

The compost produced has many chemical and physical characteristics that allow it to be used in different ways. Finished compost must be tested before they are handled for use to ensure (1) worker safety, (2) avoidance of environmental degradation, (3) maintenance of the composting process, and (4) verification of product attributes. Product attributes are those attributes that relate to safety requirements and to the marketing and use of the compost. Principal uses of compost are to mix it with soil or to use it as mulch. However, just because an organic material has undergone the composting process and is designated a "compost," doesn't necessarily mean that its use will be beneficial.

The chemical and physical characteristics of compost depend on the kind of material originally used (Bary et al., 2004). This original material is usually referred to as feedstock. Chemical and physical constituents of some compost can be detrimental to the soil environment and human health if not handled properly. Consequently, since characteristics of compost can vary greatly, tests have been developed to measure various important parameters of the compost. Parameters that are typically measured are shown in Table 7. Therefore, the main purpose of testing compost is to determine the concentrations of components and characteristics of the compost so that an evaluation of its quality can be made. Currently there are no nationally mandated requirements for testing composts. However, many states have established their own testing requirements. In some cases, classes of compost have been established with specific tests required for each class (Ohio revised code). In general, tests for composts can be organized into those that evaluate the chemical, physical, or biological characteristics of compost. A discussion of tests in each of these categories follows.

Tests of chemical characteristics

pH and nutrients

Typical ranges for pH of compost and the concentration of macronutrients in compost are given in Table 7. However, these ranges can be substantially different depending on the kinds of feedstock used. The predominant use of compost is to mix it with soil to form a good growing medium for plants. Whether or not the compost-soil mixture is a good medium for plants depends on the quality and quantity of the compost used. The pH value of the compost is important, since applying compost to the soil can alter the soil pH which in turn can affect the availability of nutrients to the plant (Riahi and Fakhari, 2004). A pH of 7.0 is neutral in reaction. A pH less than

Table 8. Interpretation of soluble salt concentrations of compost if used as greenhouse growth media.

Soluble salts results (1:5 v/v method)*	Interpretation**
dS/m (mmhos/cm)	
0.0 - 0.12	Very low; indicates very low nutrient status; seeds may germinate
0.13 - 0.34	Low; suitable range for seedlings and sensitive plants; plants may show deficiency and grow slowly
0.35 - 0.64	Desirable range for most plants, but upper range may be too high for some plants
0.65 - 0.89	Higher than desirable for most plants; loss of vigor in upper range
0.90 - 1.0	Reduced plant growth and vigor; wilting and marginal leaf burn
1.10+	Plant growth severely stunted; plants usually die

*One volume of compost to five volumes of water.
** Interpretation is different for other methods NARES, 1991.

7.0 designates an acid condition, while a greater value than 7.0 is an alkaline condition. Deciduous leaf compost tends to be slightly alkaline while coniferous leaf compost is acid. How the soil pH is altered when compost is mixed with the soil depends on the pH of the soil, its buffering capacity, the pH of the compost, how much compost is used and how thoroughly it is mixed with the soil, and how rapidly the compost breaks down in the soil environment. The pH of the soil-compost mixture should be determined with a soil test.

Important nutrients are contained in compost. The concentrations of both the macronutrients and micronutrients can be determined by testing the compost. Nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur are designated as macronutrients. The micro-nutrients are manganese, iron, zinc, copper, and boron. Usually the unit of expression is percent for macro-nutrients and mg/Kg (parts per million) for micronutrients. All of these nutrients are important to growing plants, but the macronutrient concentration of compost is usually of major interest (Buchanan, 2010). Of the macronutrients, the availability of nitrogen to plants is the most complex. Nitrogen can be found in two significant forms in the compost. It can be present in the inorganic forms of nitrate-nitrogen and ammonium-nitrogen. Immature com-post will contain more ammonium-nitrogen than mature compost. Most of the nitrogen in compost is bound within organic molecules. This form of nitrogen is often referred to as "organic nitrogen." The inorganic nitrogen forms are immediately available for absorption by plants while the availability of the organic form depends on how rapidly the microorganisms break down the compost (Insam, 2004). The rate of breakdown will depend on many factors, predominant of which are temperature and moisture. All the organically bound nitrogen in the compost is usually not available the first growing season. Depending on the feedstock, approximately 10 to 30% of the organic nitrogen is available to the plant during the growing season (Bary et al., 2004).

The nutrients of phosphorus and potassium are also very important in compost. A high percentage of these nutrients are usually available to the plant the first growing season. However, the availability may depend on the kind of soil, and the moisture and temperature of the soil (Ekinci et al., 2004). The other macronutrients of calcium and magnesium in compost are similar in their plant-availability to that of phosphorus and potassium. The concentrations of micronutrients found in compost depend on the feedstock used. Very high concentrations of micronutrients can be toxic to plants. The most toxic are boron and copper. However, these elements are bound in the organic matrix of the compost and are not readily available to the plants. Whether or not the compost should be tested for these nutrients is largely dependent on the feedstock used and the intended use of the compost (Thompson et al., 2002).

Soluble salts

The soluble salts test is a very important test. A high concentration of soluble salts in the plant growth medium is detrimental to germinating seeds and to plant growth. Death of the plant can result if the soluble salt level is too high (Table 8). Soluble salt is a term used for chemical compounds, predominantly nutrients that dissolve in water and form ions. Once the compounds have ionized, electrical current can be conducted through the solution. The soluble salts test measures the conductance of electrical current in a liquid slurry or extract from the compost. Thus, the test is often called an "electrical conductivity test." The unit of conductance is decisiemens per meter (dS/m), equivalent to mmhos/cm. The greater the electrical conductance, the greater the concentration of soluble salts in the compost.

It is a measure of the combined amount of salts in the compost. Salts that become soluble and commonly found in compost are potassium chloride; sodium chloride; various nitrates; compounds involving sulfates; and calcium, magnesium, and potassium carbonates. The kinds of feedstock influence which salt will be predominant. Feedstock that has a rich nutrient source, such as animal manure, will result in compost with higher soluble salt levels than those not containing animal

Table 9. Heavy metal concentration limits for compost proposed by the Ohio Environmental Protection Agency.

Heavy metal	(mg/Kg or ppm)
Arsenic	41
Cadmium	35
Copper	1500
Lead	300
Mercury	7.8
Nickel	420
Selenium	100
Zinc	2800

EPA, 1999.

manure. If animal fluids make up part of the feedstock, then the compost can be especially high in the soluble salts of sodium chloride and potassium chloride.

Composts that are high in soluble salts can be used with soil. However, superior management is required as compared to compost not containing high soluble salts concentration. Less amount of compost containing high levels of soluble salt should be mixed with soil as compared to composts with low soluble salt concentrations. Generally, compost containing concentrations of soluble salts of 0.35 dS/m or less is safe to use (Table 8). More intensive management in using the compost is required when the range is from 0.36 to 0.65 dS/m. The concentration of soluble salts needs to be reduced prior to use when greater than 0.65 dS/m.

Leaching the compost with water will reduce the concentration of soluble salts. In addition, the usefulness of the compost will depend on the soil to which it is added, the amount and frequency of adding the compost to the soil, the plant's tolerance to high salt concentrations, and the amounts and frequency of irrigation water or rainfall.

Carbon/Nitrogen ratio

The carbon/nitrogen ratio is not a test in itself, but requires two separate tests: the test for organically bound carbon and the test for total nitrogen. This ratio provides an indication of the kind of compost and how it must be managed when mixed with soil. Generally, composts that have carbon/nitrogen ratios greater than 30 to 1 will require additional nitrogen when mixed with the soil for the purpose of growing plants. The larger the ratio, the greater the amount of nitrogen that will be needed. The extra nitrogen allows the soil microorganisms to multiply rapidly, without taking nitrogen from the soil and causing nitrogen deficiency in the plant.

Heavy metals

A major concern about heavy metals (arsenic, cadmium, copper, lead, mercury, nickel, selenium) is that if their concentrations in edible portions of plants are excessively high, then there can be a danger to humans. A plant root mechanism operates to help protect the plant from high concentrations of some heavy metals. The plant will exhibit toxicity symptoms or even death before the heavy metal concentration would become high enough to be detrimental to the human food chain. However, some heavy metals exhibit an exception to the root barrier protection mechanism. They can be present at concentrations in the plant that would be harmful to human health without being toxic to the plant. Cadmium is a prime example. In some plants, selenium can also accumulate to very high concentrations without showing toxicity. Because of the toxic nature of excessive concentrations of heavy metals, governmental environmental protection agencies are in the process of establishing upper concentration limits in compost (Table 9).

Tests of physical characteristics

Air capacity, bulk density, water infiltration and conductivity, and water holding capacity - These tests provide information on how well the compost will retain air and water. The pore space between the compost particles should be such that optimum retention of air and water are attained. If the particles are too close together, then the compost tends to compact, resulting in low air capacity, low water infiltration and water holding capacity. These characteristics are especially important if the growing medium will be solely or principally compost. Different kinds of compost will exhibit differences in these characteristics.

Solids content

This test measures the amount of solid material in the compost and is the converse of moisture content. The quantity of solids is usually expressed as a percentage of the sample weight, oven-dried at 70 ± 5°C to constant weight. The moisture content is the value obtained from subtracting the percent solids from 100%. Knowledge of the solids content is important in storing, handling, and using the compost. Compost that has become very dry will be very dusty and it will often be resistant to rewetting and good water retention. Compost that is extremely wet for a few days will become anaerobic with the production of offensive odors.

Ash content

This test is a measure of the inorganic residual material left after burning the oven-dried compost sample at 500±50°C. The amount of ash will vary depending on the kind of feedstocks composted. Feedstock's that have a high mineral constituent, e.g., that contain soil, will have a high ash content.

Total volatile solids and biodegradable volatile solids

This test is the converse to the ash test in that it measures the quantity of the organic constituents converted to carbon dioxide at 550°C, essentially the same as the Loss on Ignition organic matter test for most compost (Thompson et al., 2002). When the inerts are removed from the sample prior to combustion, the amount of dry weight converted to carbon dioxide is termed biodegradable volatile solids. Total volatile solids are measured when the inerts are not removed prior to combustion. The results from these tests along with the results from the ash test provide information about the completeness of the composting process. However, knowledge about the kind of feedstock used along with the information from these tests is important in evaluating compost regarding its intended use.

Film plastics

This test provides an estimation of the surface area of the compost sample attributed to film plastics. Composts that contain substantial amounts of film plastics are considered poorer quality than those without film plastics. The film plastic is not only of aesthetic concern but in large enough quantities can affect soil color. Accumulations in the cultivated layer of the soil can become a moisture barrier and can wrap in tillage implements. In addition, pieces of film plastic can be injurious to birds and animals if they consume the compost (EPA, 1998).

Glass shards, metal fragments, and hard plastics inerts

This test provides an estimate of inert materials that will not break down during the composting process. Consequently, a significant percentage of these inerts in the compost will make the compost difficult and dangerous to handle, resulting in compost of little value.

Organic chemical contaminants

The effectiveness of the degradation of organic chemical contaminants by the composting process depends on the chemical structure of the contaminants. Tests are available to determine the concentration levels of various organic chemical contaminants that may be in some composts. Testing protocols are available for chlorinated herbicides, dioxins, organochlorine pesticides, organophosphorus pesticides, polychlorinated biphenyls, semi-volatile organic compounds, and volatile organic compounds. The importance of whether or not compost should be tested for any or all of these compounds largely depends on the feedstock involved and the intended use of the compost.

The most widespread concern in regard to organic contaminants involves residues of herbicides. The composting process generally does a good job of reducing herbicide residues below concentration levels that would be harmful to plants if the compost was used in the growing medium. It has been reported that diazinon and 2,4-D, the most common herbicides, are at or near the level of detection after composting (George, 2001). Other reviews have reported that although pesticide residues are found in composting feedstocks, herbicides are degraded sufficiently during composting and rarely detected (Buyuksonmez et al., 1999, Buyuksonmez et al., 2000).

In a study that involved testing 12 compost samples for 200 pesticides, only four pesticides were detected, mainly persistent chlorinated insecticides (Richard and Chadsey, 1990). The use of organochlorine class of insecticides has been banned in the United States for many years. However, in the last few years two persistent herbicide residues have been found in some composts at parts per million to sub-parts per million concentrations which are harmful to some plants. These residues are clopyralid and picloram and are from herbicides designed for broadleaf weeds found in pastures and lawns (Bezdicek et al., 2000). The common names of the herbicides containing these compounds are Confront, Curtail, Stinger, Millenium, Tansline, Tordon and Grason (Bezdicek, 2001). It is thought that these residues can be harmful to plants, depending on the kind of plant, for a year or more.

Consequently, because of the resistance of these herbicide residues to breakdown, it is important to test compost if it is thought that the compost may contain these compounds. Laboratory tests can be performed to determine the concentration of clopyralid and picloram, but they may be very expensive, depending on the detection level sought. Before doing a laboratory test, it is best to perform a bioassay with the compost (Fauci et al., 2002).

Pathogens

Organisms and microorganisms that can cause infection or disease in a susceptible host are pathogens. Examples of pathogens are yeasts, bacteria, mold, fungi, virus, protozoa, and helminthes. Pathogens are rarely found in compost at concentrations that would cause a problem in using the compost, provided the composting process is completed correctly (Ingham, 1999). However, tests for pathogens in compost are available if it is suspected that there may be a problem.

Miscellaneous characteristics

Indirect tests can be conducted that will help determine various quality characteristics of compost. These are the seed germination test that measures the ability of seeds to germinate and grow either directly in the compost or a water extract of the compost. A respirometry test is used to estimate the degree of maturity of compost. Crude tests for odor will also allow a rough judgment to be made about the quality of compost.

Conclusion

This review showed that, the maturity of compost is crucial in attaining the beneficial uses and safety during handling. Composting organic EFBs is hence an excellent way to reduce the volume of the waste and often to make it more useable than in its original form. Since composts are variable, testing is necessary to determine the meters and the variability of these parameters through time as well as the characteristics property of the compost. Compost producers that maintain records of test results over time allow for responsible use of compost. The regulations governing compost should be enforced to ascertain standard.

REFERENCES

Alexander RA (1994). Standards and guidelines for compost use. Biocycle, 35(12): 37-41.

Anon. (2000). Malaysian Palm Oil Board: Review of the Malaysian Oil Palm Industry 1999. Ministry of Primary Industries, Malaysia.

Barker AV (1997). "Composition and Uses of Compost." In Agricultural Uses of By-Products and Wastes, edited by J.E. Recheigl and H.C. MacKinnon. Washington, DC: American Chemical Society.

Bary AI, Cogger CG, Myhre EA (2004). Yard trimmings as a source of nitrogen for crop production. Compost Sci. Util., 12(1): 11-17.

B.C. Agricultural Composting Handbook (1998). Second Edition, Ministry of Agriculture and Food.

Bezdicek D, Fauci M, Caldwell D, Finch R (2000). Compost quality: New threats from persistent herbicides. Agrichem. Environ. News, 174: 9-13.

Bezdicek D, Fauci M, Caldwell D, Finch R, Lang J (2001). Persistent herbicides in compost. Biocycle, 42(7): 25-30.

Boulter JI, Trevors JT, Boland GJ (2002). Microbial studies of compost: bacterial identification, and their potential for turfgrass pathogen suppression. World J. Microbial. Biotechnol., 18(7): 661-671.

Brady NC, Weil RR (2002). The Nature and Properties of Soils, 13th edition. Upper Saddle River, NJ: Prentice-Hall.

Buyuksonmez F, Rynk R, Hess TG, Bechinski E (1999). Occurrence, degradation and fate of pesticides during composting. Part I: Composting, pesticides and pesticide degradation. Compost Sci. Utilization, 74(1): 66-82.

Buyuksonmez F, Rynk R, Hess TG, Bechinski E (2000). Occurrence, degradation and fate of pesticides during composting. Part II: Occurrence and fate of pesticides in compost and composting systems. Compost Sci. Utilization, 8(1): 61-81.

Buchanan M (2010). Composting in the home garden makes Sense. Agronomic News for North Carolina Growers — www.ncagr.gov/agronomi/ (919) 733-2655.

Damanhuri MA (1998). Hands-on experience in the production of empty fruit bunches (EFB) compost. Paper presented at the CETDEM Malaysian Organic Farming Seminar. Petaling Jaya, Selangor, Malaysia.

Deraman M (1993). Carbon pellets prepared from fibers of oil palm empty fruit bunches: 1.A quantitative X-ray diffraction analysis. PORIM Bull. Palm Oil Res. Inst. Malaysia.

Donahue RL, Follett RH, Tulloch RW (1990). Our Soils and Their Management. Danville, IL: Interstate Publishers.

EEMS (2009). Economic and Environmental Manure Solutions Cornell University, Department of Biological and Environmental Engineering, Ithaca, NY. Internet source:
http://www.bee.cornell.edu/extension/manure/composting.htm

Ekinci K, Keener HM, Michel FC, Elwell DL (2004). Modeling composting rate as a function of temperature and initial moisture content. Compost Sci. Util., 12(4): 356-364.

Environmental Protection Agency (EPA), (1998). Organic Materials Management Strategies. EPA530-R-97-003. Washington, DC: US Government Printing Office; pp. 1-53.

EPA (1999). Alternative Technologies/Uses for Manure. Office of Wastewater Management, U.S.A.

Fauci M, Bezdicek D, Caldwell D, Finch R (2002). Development of plant bioassay to detect herbicide contamination of compost at or below practical analytical detection limits. Environ. Contamination Toxicol., 68: 79-85.

Francis JL, Xiying H (2007). A review of composting as a management alternative for beef cattle feedlot manure in southern Alberta, Canada. Bioresour. Technol., 98 (17): 3221-3227.

Francou C, Poitrenaud M, Houot S (2005). Stabilization of organic matter during composting: influence of process and feedstocks. Compost Sci. Util., 13(1): 72-83.

George F (2001). New Zealand City Confronts Contamination. BioCycle, 47(7): 31.

Haug RT (1993). The Practical Handbook of Compost Engineering. London: Lewis Publishers,

Hamdan AB, Tarmizi AM, Mohd DT (1998). Empty fruit bunch mulching and nitrogen fertilizer amendment: The resultant effect on oil palm performance and soil properties. PORIM Bull. Palm Oil Res. Inst. Malaysia.

Insam H, Riddech N, Klammer S (2004). Microbiology of Composting, Springer Verlag, Berlin New York, ISBN 978-3-540-67568-6.

Ingham E (1999). Making a high quality compost tea, Part II. BioCycle. 40/4, 94.

Insam H (2004). Microbiology of composting. 2002. Springer pub. p. 632.

Kamarudin H, Mohamad H, Arifin D, Johari S (1997). An estimated availability of oil palm biomass in Malaysia. PORIM Occ. Paper Palm Oil Res. Inst. Malaysia.

Lim B (2000). The New Straits Times. Thursday, December 28, 2000.

Ma AN, Cheah SA, Chow MC (1993). Current status of palm oil processing waste management. In: Waste Managaement in Malaysia: Current Status and Prospects for Bioremediation. Yeoh

B.G. et al. (Eds.), pp. 111-136.
Ma AN, Tajima Y, Asahi M, Hanif J (1996). A novel treatment process for palm oil mill effluent. PORIM Techno, Palm Oil Res. Inst. Malaysia.
Mayer M, Hofer H, Maire U (1998). "Trends in Yard Waste Composting," Biocycle, Vol. 29.
Natural Resource, Agriculture, and Engineering Service (1991). Cooperative Extension. Composting to Reduce the Waste Stream: A Guide to Small Scale Food and Yard Waste Composting, NRAES-43, Itaca, NY: Natural Resource, Agriculture, and Engineering Service, Cooperative Extension.
Ohio revised code 3745-27-46, proposed rules.
On-Farm Composting Handbook (1992). Northeast Regional Agricultural Engineering Service - Cooperative Extension; NRAES-54.
Riahi H, Fakhari J (2004). Physical, chemical and biological studies of municipal compost. Acta Hortic., 644: 145-150.
Richard T, Chadsey M (1990). Environmental impact of yard waste composting. BioCycle, 31(4): 42-47.
Rynk R, Richard TL (2001). "Commercial Compost Production Systems." In Compost Utilization in Horticultural Cropping Systems, edited by P.J. Stofella and B.A. Kahn. Boca Raton, FL: Lewis Publishers.
Snow DA (1999) commoner's guide to backyard composting. MSW Management. pp. 16-25.
Suhaimi M, Ong HK (2001) Composting Empty Fruit Bunches of Oil Palm. FFTC Publication. Malaysian Agric. Res. Dev. inst. Malaysia 2001-11-01.
Thambirajah JJ, Zulkifli MD, Hashim MA (1995). Microbiological and biochemical changes during the composting of oil palm empty fruit bunches; effect of nitrogen supplementation on the substrate. Bioresource Technol., 52: 133-144.
Thompson WH, Leege PB, Millner P, Watson ME (2002). Test methods for the examination of composting and compost. U.S. Composting Council. [Online]. Available at http://www.tmecc.org/tmecc/ (posted 1 May 2002; verified 15 Oct. 2002).
Yusri A, Mat RA, Mohammed O, Azizah H, Kume T, Hashimoto S. (1995). Biodegradation of oil palm empty fruit bunch into compost by composite micro-organisms. Paper presented at the EU-ASEAN Conf. Combustion of Solids and Treated Product.
Zakaria ZZ, Khalid H, Hamdan AB (1994). Guidelines on land application of palm oil mill effluent (POME). PORIM Bull. Palm Oil Res. Inst. Malaysia.