

# **Evaluation of Agricultural and Agro- industrial Residues for Composting for Agricultural Use in Ghana**

**(A Case Study in the Kwaebibirem District)**

This thesis is submitted to

**School of Research and Graduate Studies**

**Faculty of Science**

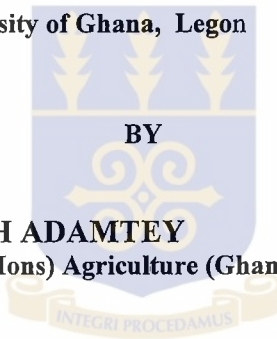
**Environmental Science Programme**

**University of Ghana, Legon**

**BY**

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**In partial fulfilment of the requirements for the award of**

**MASTER OF PHILOSOPHY DEGREE**

**IN**

**ENVIRONMENTAL SCIENCE**

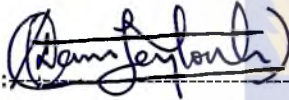
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### Declaration

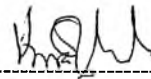
Except for references to the works of researchers which have been duly cited, this thesis is the result of my own original research work undertaken by I, Noah Adamtey of the Environmental Science Programme, University of Ghana, under the supervision of Dr. K. G. Oforu-Budu, Prof .S. K. A. Danso and Dr.P.B. Attengdem. I confirm that this thesis has neither in whole nor in part been presented for another degree elsewhere.

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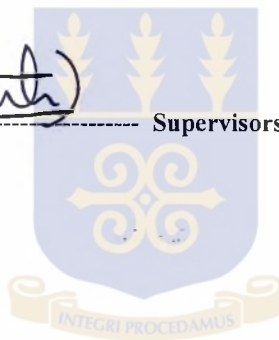
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**Dedication**

*To my children, Nancy, Harriet and Noah Jnr.*



## ACKNOWLEDGEMENT

Blessed be the name of the Lord for I set the Lord always before me throughout this study and He never forsook nor disappointed me. Rather **He** encamped me with **His** Angels throughout my studies until the goal finally surfaced. As the Bible says, the young lions do lack, and suffer hunger. But my Lord God never made me lack anything throughout my studies. **His** goodness, mercy and favour followed me throughout the studies.

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**LIST OF ABBREVIATIONS**

<b>ABBREVIATIONS</b>	<b>MEANING</b>
°C	Degree Celsius
d	Day
Eh	Electrical conductivity
g	Grams
kg	Kilograms
l	Litres
m	Metres
mg	Milligram
pH	- log of hydrogen ion concentration
%	Percent
<	Less than
>	Greater than
R <sup>2</sup>	Coefficient of determination
r	Correlation
GI	Germination index
BOD	Biological Oxygen Demand
C/N	Carbon: Nitrogen ratio
COD	Chemical Oxygen Demand
SS	Suspended Solids
TDS	Total Dissolve Solids
CEC	Cation exchange capacity
NO <sub>3</sub> -N	Nitrate nitrogen
NH <sub>4</sub> -N	Ammonium nitrogen
NH <sub>4</sub>	Ammonia
N	Nitrogen
P	Phosphorus
K	Potassium
Ca	Calcium
Mg	Magnesium
C	Carbon
CO <sub>2</sub>	Carbon dioxide
CO <sub>3</sub>	Carbonate
CH <sub>4</sub>	Methane gas
H <sub>2</sub> O	Water
H <sub>2</sub> S	Hydrogen sulphide
MgO	Magnesium oxide
O <sub>2</sub>	Oxygen
PO <sub>4</sub>	Phosphorus oxide
NO <sub>3</sub>	Nitrate
N <sub>2</sub> O	Nitrous oxide
MgSO <sub>4</sub>	Magnesium sulphate
MgCl <sub>2</sub>	Magnesium Chloride

ABBREVIATIONS	MEANING
ATP	Adenosine triphosphate
DNA	Deoxyribonucleic acid
RNA	Ribonucleic acid
CH	Cocoa Pod Husk
EFB	Empty Fruit Bunche
MF	Mesocarp Fibre
PD	Poultry Droppings
PKC	Palm Kernel Cake
POME	Palm Oil Mill Effluent
ANOVA	Analysis Of Varians
DMY	Dry Matter Yield
LSD	Least Significant Difference
NS	Non Significant
RCBD	Randomise Complete Block Design
GOPDC	Ghana Oil Palm Development Company
OPRI	Oil Palm Research Institute
PSI	Presidential Special Initiative
EPA	Environmental Protection Agency
AGRAF	Agricultural and Forestry System Division
BARC	Bestville Aerated Rapid Composting
CIRAD- CP	Centre de Coopération Internationale en Recherche Agromique pour le Development (Tree Crops Department)
EAWAG	Swiss Federal Institute for Environmental Science and Technology
ECOLAB	Ecological Laboratory, University of Ghana
FAO	Food and Agriculture Organization
IWMI	International Water Management Institute
SANDEC	Department of Water and Sanitation in Developing Countries
SMARTRI	SMART Research Institute
UGARS	University of Ghana Agric Research Station
USEPA	United State Environmental Protection
GOG	Government of Ghana
GSS	Ghana statistical service
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit
APHA	American Public Health Association
AWWA	American Water Works Association
GEMS	Global Environmental Management Systems
UNEP	United Nations Environment Programme
UNESCO	United Nation Education Scientific and Cultural Organisation
WEF	Water Environment Federation
WHO	World Health Organisation
WMO	World Maritime Organisation

## KEY WORDS

- Ammonification*- the conversion of organic nitrogen into ammonium ( $\text{NH}_4$ ) by heterotrophic micro-organisms
- Compost raw materials*- organic substances which are normally collected separately such as organic wastes, plant wastes, which enter into the composting cycling.
- Compost*- a product of decomposition process resulting from the aerobic treatment of organic materials .
- Composting*- the biological decomposition and stabilization of organic substances under conditions which allow development of thermophilic temperatures as a result of biologically produced heat, with a final product sufficiently stable for storage and application to land without adverse environmental effects.
- Decay*-anaerobic biological decomposition of organic substances accompanied by the formation of putrid gas.
- Decomposition*-the biochemical process of composting where compost raw materials are broken down and decomposed by micro-organisms.
- Denitrification* - the biological reduction of  $\text{NO}_3^-$  or  $\text{NO}_2^-$  to gaseous forms of N, usually  $\text{N}_2\text{O}$  and  $\text{N}_2$
- Fertilizers*-substances intended to be added directly or indirectly to crop plants to promote growth, increase harvest or improve quality.
- Growth*-development of plants .
- Humus*- the end product of aerobic biological decomposition processes such as composting.
- Immature compost* -compost material with a high content of easily decomposed organic
- Immobilization* - the tying up of nitrogen by soil organisms.  
materials (which can undergo intensive maturation) in maturation degree II&III. i.e. Max. Temp. of  $50-60^\circ\text{C}$  &  $40-50^\circ\text{C}$  (in the self heating test).
- Matured compost*- a product that has reached degree of completeness of composting.
- Mobilize*-the release of nitrogen.
- Nitrogen - Mineralization* - the conversion of organically bound nitrogen into plant available organic forms such as ammonium and nitrate .
- Nitrification*-the conversion of ammonium (mainly) by autotroph bacteria into nitrate and nitrate.
- Nutrient uptake*-the intake of nutrients by plants.
- Organic fertilizers*-substances made up of one or more (un) processed material(s) of a biological nature (plant/animal) and /or unprocessed mineral materials, lime, rock phosphate, etc that have been altered through a controlled microbiological decomposition process into a homogenous product.
- Organic fertilizers*-substances made up of one or more (un) processed material(s) of a biological nature (plant/animal) and /or unprocessed mineral materials, lime, rock phosphate, etc that have been altered through a controlled microbiological decomposition process into a homogenous product.
- Recycling is the regeneration of materials for purposes other than energy recovery.
- Soil additives*- materials without substantial nutrient content with a biotic, chemical or physical effect on soil.

## ABSTRACT

*Ghana produces several hundred million tons of agricultural and agro industrial residues annually. In the Kwaebibirem District in the Eastern Region of Ghana the processing of fruits of the major tree crops such as oil palm and cocoa together with the large cultivation of rice and maize generate high amounts of agricultural and agro industrial residues. Oil palm residues comprising empty fruit bunches (EFB), palm oil mill effluent (POME), mesocarp fibre (MF) and palm kernel cake (PKC) are significant among the agricultural and agro industrial residues, because of the quantities generated and their impact on the environment. The management of these residues is often a major problem for many oil producing countries. The purpose of this study was to characterize and quantify the major residues of oil palm processing, determine their impact on the environment, their potential uses in agriculture and to recommend appropriate management methods.*

*To achieve these objectives surveys were conducted through interviews and administration of questionnaires translated in the local languages. Samples of POME were taken from both large and small scale palm oil processing mills and characterised. Different combinations of the oil palm residues (EFB, MF, PKC and POME) were composted with and without cocoa pod husks (CH) or poultry waste (PW) to increase the K and P values of the compost. Rock phosphate (RP) was also used because composting was found to increase its solubility and to increase P content of compost where poultry waste was not available. Monitoring of the biochemical changes during composting was also carried out to ascertain the best indicator of maturity for such compost mixtures. The parameters monitored during composting included: pH, temperature, carbon dioxide evolution, C/N, ammonium and nitrate nitrogen concentration and seed germination index. The resultant compost treatments were tested over eight months in a field experiment (2003-2004)*

at the University of Ghana Agricultural Research Station. The effects of the compost treatments on the growth and nutrient uptake of two different oil palm varieties (OPRI and La Mé seedlings) were evaluated at the pre-nursery and the nursery stages using a Randomized Complete Block Design (RCBD). The treatments were Flanamite (imported organic fertilizer,  $T_5$ ), 15:15:15NPK ( $T_{11}$ ) and nine different compost treatments:  $T_1$ (EFB+POME),  $T_2$ (EFB +POME+MF),  $T_3$  (EFB + PKC +Water),  $T_4$  (EFB+PKC+CH+ POME),  $T_6$ (EFB + PKC + CH + PW + Water),  $T_7$ (EFB+PKC+CH+PW+POME),  $T_8$ (EFB+EFB+PKC+CH+RP+POME) , $T_9$  (EFB+PKC+POME) and  $T_{10}$ (EFB+ Water)

The findings by the author showed that about 33,025 metric tonnes of EFB and 73,229 m<sup>3</sup> of POME were generated in the Kwaebibirem District. The pH values of MF and PKC ranged between 4.5 and 6.0 while that of the fresh POME and EFB were 4.6 and 9.0. Nitrogen content of the POME ranged between 1.30-1.80%. PKC showed highest phosphorus content (0.7%) while MF recorded the least (0.20%). Potassium content was highest in EFB (2.10%) and lowest in POME (0.06%). Whereas the large scale oil palm processing mills treated their POME through anaerobic digestion, the small and medium scale oil palm processing Mills did not. The untreated POME which is usually discharged into the environment had low pH (below 5), high Electrical Conductivity ( 31,300  $\mu$ S/cm.), high Total Dissolved Solids, TDS (181,200mg/l), Chemical Oxygen Demand, COD(133,760mg/l ), Biological Oxygen Demand, BOD (44,566mg/l) and oil content (560,250mg/l) higher than critical values supplied in the Environmental Protection Agency (EPA of Ghana) for waste water quality standard guidelines for discharges into water bodies, and the Malaysian Standards for oil mill effluent for watercourse discharge. The POME was partly found to account for the high BOD (14.40mg/l), COD (166.70mg/l)

and low dissolved oxygen (0.93-1.23mg/l) of water bodies near the small scale oil palm processing Mills.

The composting mixtures matured after 138 days of composting. Correlation of maturity parameters with germination index showed that alkaline pH, CO<sub>2</sub> evolution, temperature and nitrates were found to correlate best with percent tomato seed germination test in determining the maturity of compost from agricultural and agro-industrial residues. The mixture of POME, PKC, cocoa pod husks, poultry waste or phosphate rock as composted material significantly improved the nutrient content of the compost. Percent nitrogen(N) ranged between 2% in T<sub>10</sub> to about 5% in T<sub>3</sub>. Highest phosphorus (P) was recorded in T<sub>8</sub> (4.4%) and potassium (K) in T<sub>4</sub> (3.97%).

Oil palm seedlings (OPRI and La Mé) grown in compost treatments recorded higher number of leaves, leaf width, leaf length, seedling height, bole diameter, root volume and total dry matter yield than seedlings grown on inorganic fertilizer(T<sub>11</sub>) or imported organic fertilizer (T<sub>5</sub>,Flanamite). Uptake values of NPK by La Mé seedlings were higher (920mg/plant,166 mg/plant,740 mg/plant respectively) than by OPRI seedlings (836.76 mg/plant, 95.83 mg/plant, 489.97 mg/plant respectively) in the same compost treatments. The correlations between dry matter yield (DMY) and nutrient uptake in both OPRI and La Mé seedlings were strong and positive ( $r = 0.9$  and  $0.96$  respectively). Surveys conducted with questionnaires and interviews on the perception and willingness of the managers of the mills and potential compost users (200 respondents) revealed that 92 to 96% of the respondents perceived compost as good and were ready to compost and use the compost for agricultural purposes. It is recommended therefore that composting could be considered as an effective method of managing agricultural and agro-industrial waste and in particular for the oil palm industry, it should be given utmost priority.

## CHAPTER 1: INTRODUCTION

### 1.1 BACKGROUND

Agricultural and agro-industrial residues include crop residues, animal by-products (manure, litters), wastewaters from processing plants, by-products from public and private horticulture (lawn and leaf clippings) and wood harvesting and milling (e.g., wood chips and sawdust). Increasing human populations and activities, such as concentrated animal production areas, expanding agro-industries, disposal of by-product materials are assuming greater challenges. Often these residues are applied to farmland to recover their nutrient or other agronomic values (Karlen et al., 1995; Risse et al., 2001) and it has been an accepted and recognised cultural practice for many centuries in USA and most parts of the world (Thomas and Pierzynski, 2000). However, the direct application of raw residues into the soil in some cases may cause undesirable effects such as phytotoxicity, nitrogen immobilisation, oxygen deficiency (Garcia et al., 1992; Sørensen and Amato, 2002) and may have adverse impact on the environment (air and water) (Vervoort et al., 1998). The improper disposal of organic wastes into the environment has consequently raised concern among some Scientists, Environmentalists and the Public.

### 1.2 PROBLEM STATEMENT

Ghana is an agricultural country and, as such, produces several hundred million tons of agricultural and agro - industrial residue annually. In an area in the Eastern Region of Ghana known as the Kwaebibirem District, the cultivation of food and plantation crops such as oil palm, cocoa, rubber, citrus, rice and maize and their processing results in the generation of high amounts of agricultural and agro-industrial residues. Oil palm residues which include empty fruit bunches (EFB), palm

oil mill effluent (POME), mesocarp fibre (MF) and palm kernel cake (PKC) are significant in terms of the quantity and their impact on the environment.

Based on an annual production of approximately 3,135,000 tons of fresh fruit bunches (FFB), it is estimated that 721,050 metric tonnes of EFB and 1.6 millions cubic metres of POME (Table 4.3) are produced annually in Ghana. The large scale oil Mills such as Twifo Oil Palm Plantation (TOPP) at Twifo, and the Ghana Oil Palm Development Company (GOPDC) at Kwae in Ghana dispose directly the POME through land application to oil palm plantations (Plate1.1) or after it has been treated through anaerobic digestion into ponds (Plate 1.2). On the other hand the small scale oil processing Mills do not treat the POME before discharging into the environment (Plate1.3). EFB and MF are also used by both the small scale and large scale Mills as mulch in oil palm nurseries (Plate 1.4).



Plate 1.1 Land Application of POME to Oil Palm Plantation (*Courtesy TOPP*)



Plate 1.2 Anaerobic Pond Digestion of POME (*Courtesy TOPP*)



Plate 1.3: Untreated POME Discharged into the Environment near Water Course



Plate 1.4 EFB and MF used as Mulch in Oil Palm Nursery

The problems associated with the above management methods are that because of high transport cost, the POME is only applied to a limited area of the plantation close to the Mills. Furthermore, POME generates a lot of bad odour in the immediate surroundings of the Mills. During and after heavy down pour the channels containing the POME may overflow their banks and this might lead to contamination of nearby water bodies. The pond system method of treating POME is also very expensive, as it requires skills, attention and management commitment in order to ensure that the microorganisms thrive and break down the pollutants successfully (Gert, 2002). The practise of treating and discharging POME into waterways is also a waste of valuable resources since POME contains valuable plant nutrients that may be useful for plant growth and could also lead to eutrophication of fresh waters (Maheswaran, 1997; Keu,2002). The high transportation cost of EFB to nursery fields is also a matter of concern. There are inherent problems associated with the spreading of EFB on nursery fields. It may also harbour snakes which might harm workers, or serve as breeding sites for beetles that destroy oil palm trees (Sunitha and Varghese, 1999). The EFB also takes long to decompose. Leaching of the remaining oil from MF and potassium from EFB might contaminate nearby water bodies (Tam et al., 1983). The unmanaged disposal of the residues causes land degradation, water and air pollution (Gyasi, 1987). Hodgson (2002) also attributed the high biological oxygen demand (BOD) load ( $4.38 \times 10 \text{ kg day}^{-1}$ ), high concentration of total suspended solids and low dissolved oxygen values of Kadewa River and other tributaries of Birim River in the Kwaebibirem District to the discharge of untreated POME into the water bodies. On the other hand the discharge of treated POME into Bobri River in the same district has also been observed to impact negatively on the river (Hodgson, 1998).

The rapid development of the poultry industry and the change of the business from small individual farm operations to large scale enterprises involving many acres of land and thousands of birds have introduced new problems in the handling and disposal of poultry waste such as litter and droppings. Poultry waste which formerly was dispersed over large and remote land areas is now being concentrated in small areas, frequently near urban communities. This has resulted in poultry waste being piled up at a rate faster than the farmer can dispose of. The - piled up poultry waste interferes with the beauty and aesthetic values of the physical environment and also produces offensive odour due to the generation of methane (CH<sub>4</sub>) and hydrogen sulphide (H<sub>2</sub>S) gas (Mensah et al., 2001). The objectionable smell causes the affected communities to stink. The garbage attracts domestic flies such as housefly (*Musca domestica*) and several flies associated with faeces and garbage. Runoff from the piled poultry waste during and following rainfall also contaminates waterways and underground water supplies as well as having detrimental effects on receiving water bodies (Mensah et al., 2001). Food crops such as lettuce, cabbage and onions were also observed to be contaminated with pathogens from poultry wastes (Mensah et al., 2001).

Cocoa pod husks which are the left over after the beans and placenta have been extracted are left on cocoa farms which serve as substrates for the development and spread of cocoa black pod disease pathogens (*Phytophthora palmivora* and *Phytophthora magakarya*) in Ghana. The disease is one of the most serious disorders with which farmers have to contend. It occurs to some extent in all the cocoa – growing regions of the country. The disease has been reported to account for up to about 80 % loss of the annual cocoa pods produced in some areas in Ghana (Tetteh , 2002).

### 1.3 THE AIM OF THE STUDY

The study was to:

- characterize the major residues of oil palm processing
- determine their current disposal methods
- determine their impact on the environment
- assess alternative methods of disposal such as composting with poultry waste and cocoa pod husks to be used as amendments.

### 1.4 JUSTIFICATION

Oil palm in Ghana is currently cultivated on approximately 285,000 hectares of land (Table 4.3). Of this approximately 250,000 ha is cultivated by 636,000 small scale farmers and the other 35,000 ha by four main private companies (World Bank/FAO/GOG, 2003). Kwaebibirem district is located in the moist semi deciduous vegetation zone in the Eastern Region of Ghana and has more than 40,000 hectares of land cropped to oil palm. Ghana Oil Palm Development Company (GOPDC), the largest oil palm estate in West Africa and Obooma Farm Products Limited a medium scale palm oil processing Mill and other numerous small scale palm processing Mills are located in this district. The processing of palm oil is the primary commercial product of the small-scale oil Mills and the companies. Significant amounts of residues are generated in the process. Under the current Presidential Special Initiative (PSI) programme about 100,000 hectares of land is earmarked for oil palm cultivation in the short term and 200,000 hectares in the long term (seven years and above). This implies that over 1.4 million metric tonnes of additional EFB and 3.3 million m<sup>3</sup> of POME and other residues are likely to be generated annually into the environment (calculation based on Table 4.3).

Hodgson (2002) reported on the environmental impact of the local oil palm processing industry but did not report on any possible treatment method for the residues. However, a Final Workshop and Expert Consultations on IDRC funded project on feasible options for waste composting in Accra, Kumasi and Tamale came to a conclusion that among the various waste treatment methods (incineration and energy recovery, land filling and composting), composting should be looked at as an alternative and cheaper management option (IWMI, 2004). Composting converts the organic components of waste into humus-like material to be used as soil conditioner or organic fertilizer. The nutrients contained in the residues contribute to the production of high quality compost of nitrogen content between 2.8 -3.3 % (Suhaimi and Ong, 2001; Aisueni, 2002). These nutrients sustained oil palm seedlings growth such that there were no significant differences in the growth parameters of the plants when compared to inorganic fertilizer (NPK) treated seedlings (Lim and Chan, 1993; Ma et.al., 1988). Furthermore, compost has high organic matter content that contains penicillin, uracil, proline and other organic compounds which give greater resistant to plants against unfavourable conditions, diseases and pest (Kurita, 1998). The composting process is flexible, has lower investment and operational cost as compared to land filling and incineration. If managed properly composting is environmentally friendly. Low pH and low BOD of composted POME were reported by Henson (1994).

The possibility of composting EFB and POME was reported by Suhaimi and Ong (2001) and Aisueni (2002), but no information was provided on the composting process and the best indicator to determine compost maturity. Compost maturity is the degree of completeness of composting (Brinton, 2000). It is a significant parameter use to determine compost quality (Murillo et.al., 1995). Danso et al. (2002) reported on the perception and willingness of urban and peri-urban farmers of Ghana

to use municipal compost for crop production. There is therefore the need to know more about the possibility of composting of the residues and willingness to use it for crop production.

The potential use of compost depends on several parameters such as composting materials, their qualities and possibility to use the resultant compost to promote and sustain crop growth. It is therefore important to evaluate the composting materials, the composting process and determine the maturity indices, so that the user will have little problem. The quality of compost depends on its value to provide plant nutrients, absence of contaminating seeds particularly weeds, pathogens, poisonous substances like heavy metals, and perceivable foreign bodies (Sharma et al., 1997). The chemical and physical characteristics of raw materials used in composting and the processing system have effects on the compost quality. When compost is immature (or has high content of easily decomposable organic materials) it has adverse effects on soils, crop growth and yields (Cotteine, 1981; Jiménez and Garcia, 1992) due to the emission of ammonia (Wong, 1985; Golueke, 1987), syntheses of ethylene oxide (Wong, 1985) and acetic acid (Lynch, 1978).

To ensure the suitability of the product to be used and to avoid the risks associated with immature compost, many authors have proposed microbial activity, biological, chemical and physical methods such as carbon dioxide evolution, pH, C/N ratio, temperature, moisture, humus, and colour (Garcia et al., 1992; Innanotti et al., 1993; Ayuso et al., 1996; Sharma et al., 1997; Bernal et al., 1998a; Tiquia and Tam, 2002) as parameters in determining maturity. However, most of these authors did not agree on the common indices that can be used across a wide range of products and which can be quantified. For example Innanotti et al. (1993) associated low microbial activity to compost stability whilst Delgado et al. (2002) associated it to emission of bad smells. Ayuso et al. (1996), Garcia et al. (1992) and Wong (1985)

on the other hand associated it to absence of phytotoxic substances for growing plants. Besides, the methods described are sometimes complex to use and few are reliable (Harada, 1990). Furthermore, most of the studies were conducted on municipal waste and since the types of raw materials used in composting also affect maturity and quality of compost (Garcia et al., 1992; Sanchez et al., 2001), it is important to conduct studies into reliable and simple methods that can be applicable in developing countries like Ghana to determine compost maturity.

The oil palm industry is confronted with pressure from Environmentalists and Scientists as the cultivation of the crop is causing deforestation, loss of biodiversity and land conflict (Gyasi, 1988; Rival, 2003). Because the high temperatures in the tropical and subtropical soils increase the rate of breakdown of organic matter, it is often difficult to maintain high levels of soil organic matter (Mulongoy and Merckx, 1993). Greater efforts must be made to build up high soil organic matter levels as organic matter affects almost all soil processes. The loss of plant nutrients, decreased biological activity, lower water infiltration and water holding capacity, deterioration of soil structure, increasing soil compaction and soil crusting are some of the results of low soil organic matter contents in Ghana (FAO-RAF, 2000). These with time will render most of the soils completely unproductive. The establishment of the proposed 300,000 hectares of oil palm crops under the PSI can only be achieved if the productivity of the soils is restored and maintained. Use of compost prepared from agricultural and or agro - industrial residue is therefore paramount.

## 1.5 SPECIFIC OBJECTIVES OF THE STUDY

The specific objectives of this study were:

1. To quantify the major types of residues generated by oil palm industry in the Kwabibirem district and ascertain their polluting potentials.

2. To assess the perception of the oil processing mills to compost palm wastes.
3. To assess the willingness of the public to buy compost for agricultural use.
4. To investigate the different combinations of such wastes that will produce good quality compost.
5. To evaluate the best indicator for the determination of compost maturity.
6. To assess the effects of the different compost treatments on the growth and nutrient uptake of oil palm seedlings.

#### 1.6 KEY RESEARCH QUESTIONS

1. (a) What types and how much oil palm residues are generated into the environment ?  
(b) How are the oil processing mills managing the residues?
2. (a) Which combinations of oil palm residues and other agricultural waste could produce good quality compost?  
(b) Which parameter (s) could be best used to determine compost maturity?  
(c) Is growth of oil palm seedlings in compost medium due to nutrient uptake and or increase in root volume?

#### 1.7 SCIENTIFIC HYPOTHESIS TESTED

1. Amount of oil palm residues generated into the environment is significant to cause pollution of water bodies.
2. Oil palm processing Mills and the public will be willing to compost oil palm residues and use the resultant product in agriculture.
3. Composting of oil palm residues and other agricultural waste such as cocoa pod husk and poultry waste will produce good quality compost.
4. The effect of compost on oil palm seedling growth parameters and nutrient uptake are comparable with inorganic fertilizer such as 15-15-15 NPK.

## CHAPTER 2: LITERATURE REVIEW

### 2.1 AGRICULTURAL AND AGRO-INDUSTRIAL RESIDUES

The types of agricultural and agro- industrial residues that are generated in Ghana include palm wastes, cocoa husks, sawdust, rice husks, poultry droppings and cow dung .

Based on annual production of approximately 3,135,000 tonnes of fresh oil palm fruit bunches (calculation based on average yield of 11 tonnes per hectare, Toledano et al., 2004), an estimated 721,000 tonnes of empty palm bunch is released into the environment (Table 4.3). Similarly, based on annual production of approximately 400,000 tonnes of cocoa beans (Ofosu-Budu et al., 2001), an estimated amount of 550, 750 tonnes of dry cocoa husk is produced. With the production of 1,424,700 tons of paddy in Ghana and Ivory Coast alone, 4,274,130 tonnes of rice straw is also produced (Ofosu-Budu et al., 2001). The wood industry churned out 2,001, 466 m<sup>3</sup> of sawdust in 1987 from only 8 major locations, in Ghana (Ofosu-Budu et al., 2001). The amount of poultry droppings and cow dung released to the environment is equally quite significant although data is not easily available, however, poultry population has been increasing steadily, with current population of over 18 million (GSS 2002). These agricultural and agro industrial wastes are currently not efficiently utilised but discarded indiscriminately into the environment, which pose serious environmental problems.

### 2.2 POTENTIALS OF AGRICULTURAL AND AGRO-INDUSTRIAL RESIDUES AS FERTILIZER AND SOIL CONDITIONER

The agricultural and agro-industrial residues, if managed properly, can be beneficial to agriculture, since these contain important plant nutrients such as

nitrogen, phosphorus, potassium, magnesium and other nutrients. Palm residues are the one of major and immediate concern. The residues include empty fruit bunches (EFB), palm oil mill effluent (POME), mesocarp fibre (MF) and palm kernel cake (PKC).

The EFB has a high moisture content of approximately 55-65% , high silica content and form 25% of the total palm fruit bunch . Also, it 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. POME is made up of about 95% - 96 % water, 0.6%-0. 7% oil and 4%-5% total solid including 2%-4% suspended solids, which are mainly debris from palm mesocarp (Ngan et al, 1996). Results of research conducted by various people on the nutrient composition of the palm residues are shown in Table 2.1.

Table 2.1 Chemical Composition of Some Residues

Residue	Nutrient composition							Source
	pH	C(%)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	
EFB	7.5	43.7	0.5	0.05	1.09	0.19	0.07	Suhaimi and Ong, (2001) Gert,(2002) Gert,(2002) Ngan et al.(1996)
MF			1.9	0.09	0.25		0.28	
PKC			2.7	1.3	0.75		0.5	
POME	4.7	-	0.08	0.02	0.23	0.04	0.06	

Poultry and cocoa pod husks have high macro and micro nutrients. Cocoa pod husk was found to contain 1.04 % N, 0.26 % P, 4.46% K and 9.4 meq/100g Ca (Ofosu-Budu et al., 2001). These agricultural and agro-industrial residues contain plant nutrients that are potentially available to plants. The residues have to be composted before it can be safely applied to the plants .Since the untreated residues

contain grease ,oil, solids , high pathogens and BOD that might pollute water bodies (Ma et al.,1988; Maheswaran, 1997).

## 2.3 COMPOSTING

### 2.3.1 Why Composting Agricultural and Agro- industrial Residues?

Composting is “the biological decomposition and stabilization of organic substrates under conditions which allow development of thermophilic temperatures as a result of biologically produced heat, with a final product sufficiently stable for storage and application to land without adverse environmental effects (Haug, 1980; GTZ/GFA-UMWELT, 1999).

The main reasons for composting agricultural and agro industrial wastes are to recycle the inherent nutrients and organic matter to improve the nutrient status of the soil, to stabilize the waste and control pollution, manage the waste to achieve clean healthy environment, inactivate pathogens and prevent temporary ill effects of the soil.

#### *Nutrient and land reclamation*

Nutrients present in organic residues are usually in complex organic form. Composting of these residues converts the nutrients from the organic to inorganic forms such as  $\text{NO}_3^-$  and  $\text{PO}_4^-$ , which are suitable for crop uptake (Ayuso et al., 1996; Polprasert, 1996). Compost application to plantations, is less bulky compared to the fresh residues. It builds up the soil fertility, provide optimum conditions for the cultivation of crops, and finally creates business opportunities for the communities.

### *Waste (or residue) stabilization and pollution control*

Raw or uncomposted residues show high values of both organic matter and total organic carbon (Ayuso et al. 1996). The uncomposted residues when applied fresh onto the land will be washed off by runoff water when it rains heavily into water bodies causing pollution like that of mineral fertilizers (Lampe, 1996; Mensah et al., 2001). The biological reactions occurring during composting will convert the putrescible forms of organic wastes into humus which is more stable and may cause little or no pollution if discharge on the land (Polprasert, 1996).

### *Clean healthy environment*

The use of the organic fractions of waste to produce compost will reduce the quantity of waste transported into sanitary landfill sites thereby prolonging the lifespan of landfills. Composting if done properly will reduce the volume of waste and ensure clean, healthy environment.

### *Pathogen inactivation*

Organic residues contain pathogens and eggs of parasites that could pose serious health hazards to human population. They also contain germination inhibiting substances i.e. phytotoxic organic metabolites (Zucconi et al., 1981a; Garcia et al., 1992; Marambe and Ando ,1992; Ayuso, et al., 1996) which might affect crop production. Some phytotoxic metabolites are acted upon by microbes during composting thereby inactivating them or reducing their concentration (Garcia et al. 1992; Ayuso et al. 1996). During composting the biological heat produced can reach a temperature of about 65°C, which is sufficient to inactivate most pathogenic bacteria, viruses and helminthic ova (Sterrett, et al., 1983; Polprasert, 1996) which otherwise could infect the workers. Therefore the composted products can be safely disposed of on land, or used as fertilizers for plant growth.

*Prevention of temporary ill - effects on both the physical and chemical properties of soil*

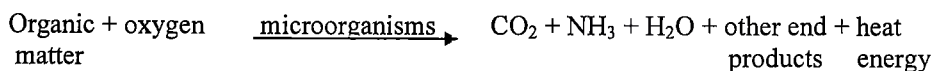
The incorporation of large quantities of plant residues such as EFB, MF, and rice husk, (which are rich in carbon) to the soil may have temporary ill - effects on both the chemical and physical properties of soil. The fresh residues, which are abundant in energy-giving carbohydrate, stimulate the growth of microorganisms, which compete with plants for the available elements such as nitrogen and phosphorus. This for a short period might lead to nitrogen immobilisation, oxygen deficiency and increases soil temperature (Negro et al., 1999; Sørensen and Amato, 2002).

### **2.3.2 Classification of Composting**

Composting can be classified into (i) aerobic composting and (ii) an aerobic digesting.

#### **(i) *Aerobic composting***

Aerobic composting is the decomposition of organic wastes by microbes in the presence of oxygen (air). The end products of aerobic composting are CO<sub>2</sub>, NH<sub>3</sub>, water, stabilised organic matter often called humus and heat (Polprasert, 1996). Below is a generalised equation for aerobic decomposition of organic matter during composting process.

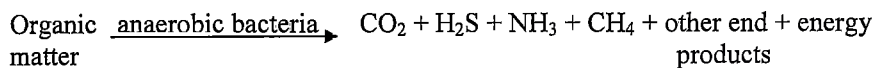


Source: Polprasert, (1996)

Some of the aerobic composting systems currently in operation are Chinese composting pile, windrow composting, force air aeration composting, the Dano system and the Jersey system (Polprasert, 1996).

**(ii) Anaerobic digesting**

Anaerobic digesting is the decomposition of organic waste in the absence of oxygen. The end products are methane (CH<sub>4</sub>), CO<sub>2</sub>, NH<sub>3</sub>, trace amounts of other gases, and other low-molecular-weight organic acids. Below is a generalised equation provided by Polprasert (1996).

**2.3.3 Composting Process**

Composting process involves preparation of solid waste, decomposition and product preparation for market. The solid waste preparation involves cutting of the composting materials into pieces and addition of other nutrient rich materials that have low C: N ratio such as POME, poultry droppings or cocoa pod husks. The decomposition is achieved by micro -organisms, mostly under aerobic conditions. There are four important stages in the decomposition processes: (i) the initial stage, when the raw materials has not yet undergone any decomposition (ii) the thermophilic phase, when the materials reach maximum temperature(>40°C) and are degraded most rapidly (iii) the end of the bio-oxidative phase, which is marked by a fall in temperature to values close to the external temperature and (iv) the maturation phase, which is a lengthy period of stabilization intended to produce a highly stabilized and humified mature compost (Bernal et al.,1998a).

The composting process can also be discussed in terms of two well defined phases, namely,(i) mineralization and (ii) humification (Sharma et al.,1997).

Mineralization is a very intensive process involving the degradation of readily fermentable organic substances like sugars, amino acids, etc. The degradation is followed by intensive microbial activities producing heat, carbon dioxide and water, along with partially transformed and stabilised product. When the assimilable

organic fraction is exhausted, some of the cells undergo decay by oxidation to provide energy for the remaining cells (Sharma et al., 1997). Transformation process of the organic substances is completed in the second phase under less oxidative conditions, thus allowing the formation of the humic characterised substance and eliminating the dense toxic compost, eventually formed during the first phase (Sharma et al., 1997). The humification phase is where we have specific micro-organisms synthesising the complex tri-dimensional polymers in the compost. Below is a biochemical reaction showing the breakdown of proteins and carbohydrates.

Proteins → Peptides → amino acids → ammonium compounds → bacterial protoplasm & ammonia.

Carbohydrates → simple sugars → organic acids → CO<sub>2</sub> and bacterial protoplasm

The precise details of the biochemical changes taking place during the complex processes of composting are still lacking. The phases, which can be distinguished in the composting processes according to temperature patterns, are shown in Figure 2. 1. Materials which are highly putrescible break down quickly, generate much heat and reach high temperatures with fairly small quantities of wastes. By contrast, starchy and woody materials release their heat more slowly and hence require larger quantities in order to produce adequate temperatures for pathogen destruction.

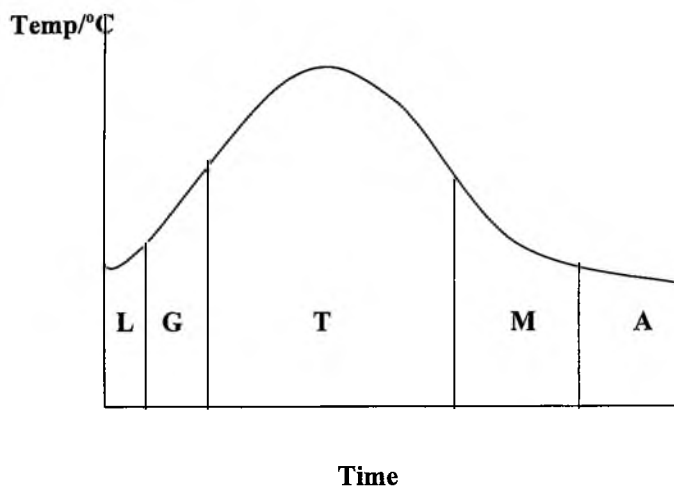


Figure 2. 1: Patterns of Temperature and Microbial Growth in Compost Piles

*Latent phase (L)*: corresponds to the time necessary for the microorganisms to acclimatise and colonize in the new environment in the compost heap.

*Growth phase(G)*: which is characterised by the rise of biologically, produced temperature to mesophilic level (25-40° C).

*Thermophilic phase(T)*: temperature rises to the highest level (50-65° C). This is the phase where waste stabilization and pathogen destruction are most effective.

*Maturation phase(M)*:where the temperature decreases to mesophilic level and, subsequently to ambient levels(A).

#### 2.3.4 Biological Succession during Composting

The organisms involved in composting may include bacteria, fungi, protozoa, invertebrates, nematodes, earthworms, mites, and various other organisms (Polprasert, 1996). The organic waste is initially acted on by the first level consumers such as bacteria, fungi (molds), and actinomycetes. Waste stabilization is accomplished mainly through bacterial activities. Mesophilic bacteria are the first to appear. As the temperature rises, thermophilic bacteria appear. Thermophilic fungi usually grow after 5-10 days of composting (Polprasert, 1996). If the temperature

becomes too high i.e. greater than 65-70°C, fungi, actinomycetes, and most bacteria become inactive and only spore-forming bacteria can develop. In the final stages, as the temperature declines, members of the actinomycetes become the dominant group, which may give the heap surface a white or grey appearance (Polprasert, 1996). Thermophilic bacteria, mostly *Bacillus spp.* (Strom, 1985), play a major role in the decomposition of proteins and other carbohydrate compounds. In spite of being confined primarily to the outer layers of the compost piles and becoming active only during the later part of the composting process, fungi and actinomycetes play an important role in decomposing cellulose, lignins, and other more resistant materials. The common species of actinomycetes are reported to be *Streptomyces* and *Thermoactinomyces*, while *Aspergillus* is the common fungus species (Strom, 1985). After these stages the first-level consumers become the food of second level consumers, such as mites, beetles, nematodes, protozoa, and rotifers. Third-level consumers, such as centipedes, rove beetles and ants, prey on the second-level consumers (Polprasert, 1996). In order for the composting process to function effectively a suitable number and species of organisms capable of attacking the types of wastes to be stabilised should be present. These organisms are naturally present in the wastes therefore compost seeding is usually not necessary. Although packages of compost inoculants are commercially available, controlled scientific tests have showed no increased benefits over natural sources (Dindal, 1978). Some types of agricultural wastes such as rice straw, leaves, and aquatic weeds, which may not readily have these organisms, may require seeding at the starting period.

### **2.3.5 Factors that Influence Composting**

The effectiveness of a composting process is dependent upon several factors including the groups of decomposing organism that inhabit and stabilise the organic

wastes. Biological, chemical and physical conditions in the compost piles, which are favourable for microbial growth, could affect the composting process. The major factors that need to be controlled in composting process include surface area and particle size, temperature, moisture, aeration, pH, carbon –nitrogen ratio and agitation.

### *Surface Area and Particle size*

Microbial activity occurs at the interface of particle surfaces and air. The surface area of material to be composted can be increased by breaking it into smaller pieces, or by other means. Increased surface area allows the microorganisms to digest more material, multiply faster and generate more heat (MOFA, 1996). Generally the smaller the size, the more fragile the particles of organic material, the greater the biological activity and rate of composting (MOFA, 1996). Materials can be chopped, shredded, split or bruised to increase their surface areas. Very small particles, however, pack tightly together so that the spaces between them will be small and narrow. This prevents the movement of air into the composting heap and the movement of carbon dioxide out of the heap (Polprasert, 1996). If the particles size is very large, the surface area for attack is much reduced; the reaction will then proceed slowly or may stop altogether (Polprasert, 1996). Therefore agricultural wastes such as straws and palm bunches, should be cut into smaller pieces prior to being composted.

### *Temperature*

When organic material is gathered together for compostin, some of the energy released by the microbial breakdown of the material is given off as heat and this causes a rise in temperature. The biologically produced heat generated within a composting mass is important for two main reasons; to maximise decomposition rate,

and to produce a material which is microbiologically 'safe' for use. It is generally known that compost temperatures greater than 60-65°C, above thermophilic range, will significantly reduce the rate of decomposition in compost piles (McKinley et al., 1985). On the other hand, most pathogenic microorganisms are inactivated effectively at temperatures above 50°C. So the key concern is to control temperatures in the compost piles in such a way as to optimise both the breaking down of organic material and pathogen inactivation (approximately 55°C) ( Polprasert, 1996). Temperature can be controlled by the adjustment of aeration and moisture content, and the utilisation of screened compost as insulation cover of the compost piles. Temperature patterns in compost piles influence the types and species of microorganisms' growth. Mesophilic temperature (25-45°C) is developed first in composting, followed by thermophilic temperature (50-65°C). After this phase most organic substrates will have been stabilised, resulting in a temperature decrease to mesophilic and eventually to ambient level. In many cases the thermophilic temperature can even reach 55-65°C and last for a few days, causing an effective inactivation of the pathogens.

#### *Moisture content*

All organisms require water for life. Water is also needed to dissolve nutrients and cell protoplasm in a compost pile. At moisture contents below 40 percent on a fresh weight basis the biological reactions in a compost heap slow down considerably and will cease entirely below 15 percent (MOFA, 1996). Higher moisture content above 60 percent also causes leaching of nutrients, reduction in air volume and produce odours (due to anaerobic conditions), and decomposition is slowed (MOFA, 1996). A moisture content between 50 and 60 percent of the organic waste is most suitable for composting and should be maintained during the

periods of active bacterial reactions i.e. mesophilic and thermophilic growth (Finstein et al., 1980; Bertoldi et al., 1983; Golueke and Diaz, 1987; Polprasert, 1996).

The maximum practical moisture content depends on the structural wet strength of the materials. Weak materials, such as paper, collapse readily on composting, the pores fill with water and anaerobic conditions set in. Sludge and animal manure usually have moisture contents higher than the optimum value of 60 percent, the addition of organic amendments and bulking materials will help reduce the moisture content to a certain degree. On the other hand, stiff materials such as straw and twigs, have moisture contents lower than 60 percent. As a result, they retain their wet strength for a long time and can be composted at high moisture contents.

#### *Aeration requirement*

Aerobic composting needs proper aeration to provide sufficient oxygen for the aerobic microbes to stabilise the organic wastes or residues and to flush out the carbon dioxide produced. Absence of air (anaerobic conditions) will lead to different types of micro-organisms developing, causing either acidic preservation or putrefaction of the heap producing bad odours.

During the first phase of composting, sufficient oxygen is needed to allow a good start for the microbial transformation as well as to promote appropriate temperature rise, needed to inactivate pathogens. Minimum oxygen content in the compost of 18% is recommended (Finstein et al., 1980; Bertoldi et al., 1983; Golueke and Diaz, 1987; Polprasert, 1996). This is accomplished through periodic turning of the compost piles; insertion of perforated bamboo poles into the compost piles; or the dropping of compost heaps from floor to floor. A more effective,

mechanical way is forced-air aeration, in which air is pumped through perforated pipes and orifices into the compost heaps. On the other hand, the process of humus formation under aerobic and micro-aerobic conditions (less oxidisable) is preferred during the second phase (Sharma et al., 1997). This is necessary to avoid excessive mineralization of the organic substance.

#### *pH range of the waste material and composting pile*

pH is the measure of acidity (or alkalinity) or hydrogen ion of a soil or compost (on a logarithmic scale). The pH scale ranges from 0 to 14, with a pH of 7 indicating neutrality. Microbes operate best within a certain range of pH.

Aerobic composting normally proceeds at pH around neutral, and rarely encounters extreme pH drop or rise. Depending on the waste you can adjust the pH by adding lime or ash. A slight pH drop may occur during the first few days of composting due to the production of carbon dioxide and organic acids (Sharma et al., 1997) such as volatile fatty acids. As the process progresses, the pH value reaches even up to 8-8.5 mainly due to the decomposition of proteins, as well as elimination of the carbon dioxide (Sharma et al., 1997). After this period the pH becomes neutral again when these acids have been converted to methane and CO<sub>2</sub> by the reactions of methane-forming bacteria (Polprasert, 1996). Optimal composting is achieved in the pH range 5.5-8. Bacteria prefer a near neutral pH, whereas fungi develop better in a slightly acidic environment (Polprasert, 1996).

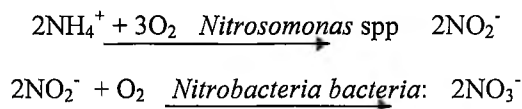
#### *C/N ratio*

The composting process depends upon the action of micro-organisms which require a source of carbon to provide energy and material for new cells, together with a supply of nitrogen for cell proteins. It is desirable that the ratio of carbon to nitrogen (C/N) is in the range of 26-30 in the initial mixture (Mote and Griffis,

1980). Excessive carbon such as the presence of sawdust and wheat straw with C/N ratios between 200-500 and 125-150, respectively, slows down microbial activities. The microorganisms will have growth limitations due to lack of nitrogen. They will have to go through many life cycles, oxidizing the excessive C until a final C/N ratio of about 10 is reached in the composted products. Therefore an extra composting time is needed, and a smaller quantity of final humus is obtained. On the other hand excessive nitrogen, as a result of materials that have C/N ratio lower than optimum (such as sludge) will allow rapid decomposition, and may cause big nitrogen loss as  $\text{NH}_3$  through volatilization (Sharma et al., 1997) under high temperatures, high pH and forced aeration: hence a loss of the valuable nutrient to atmosphere. The simplest method of adjusting the C/N ratio is to mix together different materials of high and low carbon and nitrogen contents. For example, straw materials which have a high C/N ratio can be mixed with materials such as manures and dung which have low C:N ratios.

Most of the nitrogen found in a composting mixture is organic, principally as part of the structure of proteins and peptides. A small part of this organic nitrogen is mineralised to ammonia by *ammonification* reactions resulting from the microbial activity developed. The ammonia thus formed undergoes different processes depending on the condition of the mixture being composted. For example, it may be dissolved (as ammonium) and then, *immobilised* by the microorganisms of the mixture, which use it as nitrogen source and transform it again into organic nitrogen. Alternatively, it may be volatilised and be given off, as happens when the mixture is at a high temperature with a pH of above 7.5 (Witter and López-Real, 1987). Lastly the ammonium may be transformed into nitrate by nitrifying bacteria when the temperature of composting mixture is below 40°C and when aeration conditions are favourable (Sánchez-Monedero, 2001). Lack of oxygen leads organisms to use

nitrate as an oxygen source, which results in *denitrification* while *nitrification stops* (Tisdale et al., 2002). During the nitrification process, the nitrifying bacteria lower the pH of the medium due to the liberation of hydrogen ions, a process which can be summarised in the following equations:



Of these nitrogen transformations, those undergone by the inorganic forms, ammonium and nitrate are the most interesting from an agricultural point of view as they can be assimilated directly by the root system of plants. Furthermore, the nitrification process has been suggested as one of the maturity indices for composting (Finstien and Miller, 1985; Bernal et al., 1998a).

### *Agitation*

In composting systems that rely upon natural air flows the lower central regions of the heap may be short of oxygen because the amount of air moving into the heap is inadequate. In such cases turning the material by hand or by machine allows air to reach these areas. Agitation also helps to break up larger pieces of material, exposing fresh surfaces to attack by the organisms (.....). Control of the agitation of the heap ensures that most of the material is subjected to the highest temperature reached. However, too much agitation can lead to excessive cooling and drying of the composting material.

### **2.3.6 Compost maturity**

Complaints of injurious effect of compost obtained from organic fraction of Municipal Solid Waste (MSW) and the occasional injuries caused by the application of compost to existing plants or germinating crops are greatly reducing the potential

use of compost as organic fertilizer (De Bertoldi and Zucconi, 1980). The most frequent causes of the adverse effects on crop yields are attributed to the agronomic use of immature compost. Immature compost is the one that has the organic matter not sufficiently mineralised.

Immature and poorly stabilised composts pose problems during storage, marketing and use. In storage, immature composts may become anaerobic which often leads to odours and/or the development of toxic compounds, as well as bag swelling and bursting (Brinton, 2000). It may also heat up in pallets during shipment. According to Jimenéz and Garcia (1992) biological blockage of soil-available nitrogen by microbial populations may occur when immature compost is applied. In addition, the application of immature compost may lead to a decrease of the oxygen (O<sub>2</sub>) concentration and the soil electrical conductivity (EC) as well as the creation of anaerobic environments at the level of the root system (Ahrens and Farkasdy, 1969). Immature compost increases the solubility of several heavy metals (Cottein, 1981). Van Assche and Uyttbroek (1981) reported that immature compost increases absorption and concentration of heavy metals in plants. With increase of soil temperature this gives rise to an inhibition of plant seed germination (Jimenéz and Garcia, 1992). Plants react to the inhibitory environmental conditions by lowering their metabolic rate, reducing root respiration, decreasing nutrient absorption, slowing gibberellins and cytokins synthesis and transport to the aerial parts (Jimenéz and Garcia, 1992).

The presence of phytotoxic compounds is one of the causes of the damages noted on the application of immature compost to soils ( Jimenéz and Garcia ,1992). Similar effects have been observed with other types of residues: animal manure (Maureen et al, 1982) and city refuse compost (Zucconi et al., 1981 a & b; de Vleeschauwer et al., 1981; Wong, 1985; Wong and Chu, 1985). Studies carried out

so far have made it clear that the phytotoxic effect of immature compost is due among others to the emission of ammonia (Golueke, 1987; Wong 1985). The presence of ammonia in the soil even in small quantities caused toxicity to the roots and normal development of plants (Van der Eerden, 1982) and to seed germination (Zucconi et al., 1981a). Similarly, ethylene oxide, which is synthesized during decomposition of immature compost in the soil, has also been reported to account for phytotoxic effect (Wong, 1985). Likewise organic acids such as acetic acid (Lynch, 1978; de Vleeschauwer et al., 1981) propionic and n-butyric acids (Chauyasak et al., 1981 ab). To avoid the above-mentioned problems it is essential to develop quick, reliable and simple methods to determine the degree of maturity of compost.

Compost maturity is beginning to be more recognized as a significant parameter to evaluate compost quality (Murillo et al., 1995). The California Compost Quality Council (CCQC) in conjunction with Woods End Laboratory and other peer-reviewers defined maturity *as the degree of completeness of composting* (Brinton, 2000). Mature compost directly affects soil pH and the supply of mineral nutrient elements, and is thus expected to increase the fertility of a soil to which the compost is applied (Kostov et al., 1996). Moreover, it does not have some of the disadvantages of chemical fertilizers such as potential burning effects and high salt content (Jarvis, 1996). Many authors have proposed microbial activity, biological, chemical and physical methods such as carbon dioxide evolution, pH, C/N ratio, temperature, moisture, humus, and colour to determine compost maturity (Sessay et al., 1997; Sharma et al., 1997; Bernal et al., 1998a; Tiquia and Tam, 2002). An insufficiently matured compost has strong demand for oxygen and high CO<sub>2</sub> production rates due to intense development of micro-organisms as a consequence of the abundance of easily biodegradable compounds in the raw material (Bernal et al., 1998a). For this reason, O<sub>2</sub> consumption or CO<sub>2</sub> production are used to determine

compost stability and maturity (Hue and Liu,1995).When temperature of the compost pile remains more or less constant and does not vary with turning of the materials a compost is considered matured (Stickelberger,1975). Jimenéz and Garcia (1991) also reported that the period in which practical temperature stabilization is achieved with a C/N ratio lower than 6 and a CEC value higher than  $60\text{meq } 100\text{g}^{-1}$ , on an ash basis , may constitute the most valid criterion for establishing the optimum degree of maturity. Similarly, Sánchez-Monedero et al. (2001) reported that compost is matured when ammonium nitrogen concentration decreased with an increased in concentrations of  $\text{NO}_3\text{-N}$  reaching values between 0.12-0.52 percent. According to Zucconi and de Bertoldi (1987), the highest concentration of  $\text{NH}_4\text{-N}$  in matured compost should not exceed 0.04%. The  $\text{NH}_4\text{-N}$  and  $\text{NO}_3\text{-N}$  ratio of 0.16 has also been used as an indicator for determining compost maturity (Bernal et al.,1998a. Golueke, (1981) Sharma et al. (1997) and Inbar et al. (1990) also reported that a good quality and mature compost has a C/N ratio of the order of 15-20. Meanwhile, C/N ratio value less than 12 has also been recommended by Jimenéz and Garcia (1992). The same authors also recommended that cation exchange capacity (CEC) less than 67 is a good indicator to determine compost maturity. Similarly, compost that maintains an alkaline pH for 24 hours is considered sufficiently matured (Jann et al., 1995).In much the same way Zucconi et al. (1981ab) recommended that compost with germination index (GI) above 50% should be considered matured .Conversely, Tiquia et al. (1996) rather recommended GI value of 80 to 85%. The maturity analyses reported by the above authors were conducted on municipal solid waste compost and under different climatic conditions . It is therefore very necessary to determine simple but reliable maturity indices for mature compost from agricultural and agro industrial wastes in a tropical West African country like Ghana.

### 2.3.7 Quality of Compost

Good quality compost should ensure a high crop yield on a sustainable basis. Quality depends on the desired properties of the compost such as essential plant nutrients (N, P, K, Ca, Mg and trace elements), absence of seeds, pathogens, perceivable foreign bodies, poisonous substances, concentration of heavy metals and pesticide, and odour. Compost should be easy to apply, homogeneous in quality, and not dusty (van Os , 1996).

Due to increasing interest in compost there seems to be an increasing need to scientifically report compost quality. Adequate scientific data is needed to guide the type and mixtures of composting materials to be used, composting processes, product quality and storage in order to establish standards. For instance, Nunan (2000) suggested policy measures to guide the use of urban organic waste. Yhdego (1994) investigated the possibility of using institutional waste in composting, Lima et al. (2004) reported on the quality of compost produced from sorted and non-sorted organic waste. Smith et al. (2001) also showed how different composting material mixtures and turning affect compost quality. Suhaimi and Ong (2001) and Manios (2004) similarly evaluated the quality of compost produced from different organic solid wastes from agriculture. Lutz (1981) reported on the use of compost with special consideration to heavy metals. Richard and Woodbury (1992) studied the impacts of different separating strategies on trace metal concentrations in municipal solid waste compost. Guar (1980) in a study to improve urban waste compost used rock phosphate and sewage sludge to raise nitrogen content from 0.8 to 1.45 percent, and Wei et al. (2000) proposed the combined use of inorganic fertilizer and compost on the field.

In Europe, quality and marketing of compost are the most crucial issues (Bath, 2004). To compete with activities of peat-based, soil-based and bark industries, compost plants need to undertake common efforts to improve on their compost quality (Bath, 2004). Nunan (2000) suggested that the quality of compost required should be investigated as part of a market research.

## 2.4 USES OF COMPOST

Compost has been a valuable soil amendment agent for centuries (USEPA, 1997). Most people are aware that the use of compost is an effective means to improve plant growth. Good quality compost improves soil fertility, crop yield and product quality (Allievi et al., 1993). Compost-enriched soil can also reduce erosion, alleviate soil compaction (USEPA, 1997; Abdelhamid et al., 2004) and help control disease and pest infestation in plants (Hoitink et al., 1993; Boulter et al., 2000). These beneficial effects of compost can increase plant production, save money, reduce the use of chemical fertilizers, and conserve natural resources. Compost used for a specific purpose or with a particular soil type works best when it is specially designed. For example, compost that is intended to prevent erosion might not provide the best results when used to grow crops and vice versa. The various purposes through which compost may be used for include soil recovery or erosion control, lawns establishment, reforestation and agriculture.

### 2.4.1 Using Compost to Control Erosion

Erosion is a naturally occurring process. However, it is often aggravated by activities such as road building and establishment of residential and commercial facilities. At the beginning of some construction projects, all vegetation and topsoil are removed, leaving the subsoil vulnerable to the agents of erosion. On steep

embankments along roads and highways, compost can be more effective than traditional mulch at reducing erosion and establishing turf because compost forms a thicker, more permanent growth due to its ability to improve the structure of the soil (USEPA,1997 ; Abdelhamid et al., 2004). Depending on the length and height of a particular slope, a 5-7cm layer of mature compost, screened to 1.7- 2cm and placed directly on top of the soil, has been shown to control erosion by enhancing planted or volunteer vegetation growth (USEPA, 1997). On steep slopes, mounds of compost at the top or bottom of slopes can be used to slow the speed of water and provide additional protection for receiving waters. Because of its ability to retain moisture (Zougmore et al., 2004), compost also helps protect soil from wind erosion during droughts.

#### **2.4.2 Using Compost to Alleviate Soil Compaction**

Compacted soil was reported to impede plant growth by inhibiting the movement of air, water, and nutrients within the soil (USEPA, 1997). Bare soil, weeds, increased runoff, and puddling after heavy rains are some of the signs of a soil compaction problem. Traditional methods such as hoeing for alleviating soil compaction are labour-intensive and expensive, and provide short-term solutions. Some turf managers are starting to use compost and compost amended with bulking agents, such as wood chips, as cost-effective alternatives (USEPA, 1997; Awuye, 2004). Incorporating composts into compacted soils was found to improve root penetration and plant establishment, as well as increased water absorption and drainage, and enhanced resistance to pests and disease (Nelson, 1992). Using compost was also indicated to significantly reduce the cost associated with turf management (USEPA, 1997; Awuye, 2004). Research conducted at a U.S. Air Force golf course in Colorado Springs, Colorado, for example, showed that turf grown in

areas improved with compost required up to 30 per cent less water, fertilizer, and pesticides than turf treated conventionally (USEPA, 1997).

### **2.4.3 Using Compost in Landscaping Activities**

Supplies of high-quality, low-cost topsoil is declining, particularly in urban areas where the demand is greatest. Compost is, therefore, becoming important in applications requiring large amounts of topsoil. Increasingly, compost is being used as an alternative to natural topsoil in new construction, landscape renovations, golf and football fields and container gardens. Using compost in these types of applications is not only less expensive than purchasing topsoil, but it can often produce better results when trying to establish a healthy vegetative cover (Awuye, 2004). After a lawn or garden has been established, maintaining it can be a challenge for both home gardeners and commercial landscape contractors. While aeration, topdressing, and chemical fertilizer applications are some of the techniques commonly employed in landscaping applications (USEPA, 1997), compost can be an effective alternative. Compost is also an effective landscaping mulch (Agassi et al., 2004). Placed over the roots of plants, compost mulch conserves water and stabilizes soil temperatures (Zougmore et al., 2004). In addition, compost mulch keeps plants healthy by controlling weeds and providing a slow release of nutrients (Agassi et al., 2004).

### **2.4.4 Use of Compost in Reforestation, Wetlands Restoration, and Habitat Revitalization**

Compost, with its high organic matter content, can absorb up to four times its weight of water and can replace essential organic material in wetlands (USEPA, 1997). In addition to wetlands restoration, compost also can help restore forests and revitalize habitats. Compost can play an important role in reforestation efforts by

providing an excellent growing medium for young seedlings. In the same way, compost can help to revegetate barren habitats (Ayuso et al., 1996), providing the necessary sustenance for native wildlife populations (USEPA, 1997). By enhancing the chemical and mineral properties of soil (Abdelhamid et al., 2004), compost facilitates native plant growth, which provides food for native and endangered animal populations (USEPA, 1997).

#### **2.4.5 Use of Compost in Agriculture**

Waste product reuse in agriculture has been widely investigated in developed countries. For example, Nogales et al. (1984) and Chanyasak and Kubota (1983) showed that the application of compost to rye grass and fruits increased crop yields. Same observations were made on tomatoes and lettuce (Ofosu-Budu and Adamtey, 2002; Kotei, 2003; Owusu, 2003). Use of compost has been reported to be an interesting approach to improve water infiltration and plant water use efficiency (Bationo et al., 2003). According to Zougmore et al. (2004), compost application improves soil water storage in the root zone of sorghum (0-80cm) under well distributed rainfall.

A study conducted by Atiyeh et al. (2002) on the influence of humic acid derived from earthworm-processed organic waste concluded that growth responses of plants were probably due to hormone-like activity of humic acids from the vermicomposts or could have been due to plant growth hormones adsorbed onto humates. On the other hand, Nardi et al. (2002) attributed the stimulatory effect of humic substances on plant growth and development to low molecular size fractions of humic substances in the plasma membrane of the plants, which positively influenced the uptake of some nutrients, and in particular that of nitrate as well as

hormone like activity. Eric et al. (2002) also, reported that organic amendments may have the potential to increase availability of soil-P to plants and Motavilli (1993) reported that organic manure such as compost increased plant uptake of P and K.

Compost materials have been used to control many soil borne plant pathogens (Hoitink et al., 1993; Boulter et al., 2000). Thus, *Phytophthora* disease incidence and severity was controlled by using compost (Kim et al., 1997), and dumping-off of smooth-skinned and wrinkled pea cultivars caused mainly by *Rhizoctonia solani* and *Pythium ultimum* by using composted sewage sludge (Lewis et al., 1992).

## 2.5 THE OIL PALM

The oil palm, *Elaeis guineensis* Jacq., originates from the west coast of Africa (Hartley, 1988). It is a monocotyledonous plant belonging to the family *Palmae* (Tomlinson, 1961). Two different oils are extracted from the oil palm fruits, palm oil and palm kernel oil. Both oils are semi solid at ambient temperature, and are generally refined by physical refining, then bleached and deodorised. Palm oil and palm kernel oil are largely used in domestic and industrial pastry making. About 90% of the world's palm oil is used for edible purposes (Sambanthamurthi et al., 2000). In non-food applications, they are ideal raw materials for oleochemicals used in numerous industrial sectors. Fatty acids, esters and alcohols, along with glycerol, are used in the cosmetics industry, soap making detergents, but also in rubber processing, candle making, the pharmaceutical industry, textiles, plastics and lubricants (Noel, 2003).

### 2.5.1 Oil Palm Agro -industry in the World

Oil palm cultivation worldwide has witnessed a very dynamic performance during the last decade. Total area under oil palm cultivation almost doubled from 3.7 million hectares in 1991 to 7.0 million hectares in 2001 (Bolívar and Cuellar-Mejía, 2003), representing a 6.6% average annual expansion. Leading this growth was Asia, which recorded an annual increase of 7.8%, from 2.7 million hectares in 1991 to 5.7 million hectares in 2001, increasing its global share from 73.3% to 81.9% of the total during the covered period (Bolívar and Cuellar-Mejía, 2003). Latin America recorded an annual growth of 5.4% (from 259 to 437 thousand hectares). Africa's total area production also rose by 3.2% yearly during 1991-1996, and from 1997 onwards its performance was very sluggish (0.5% annual variation) as compared to

the other two continents (Bolívar and Cuellar-Mejía, 2003). Ghana's total area under oil palm production increased from 42,766 ha in 1989 to 48,395 ha in 1996/97 and is currently to 285,000 ha (Toledano et al., 2004).

### **2.5.2 Challenges Facing the International Oil Palm Commodity Chain**

Among the challenges facing the oil palm industry include increasing pressure from environmentalists. The oil palm industry is confronted with deforestation, conservation biodiversity, effluent management, land conflict and food safety (Rival, 2003). Loss of biodiversity, conflict over land and pollution of water bodies are the major challenges facing the local industry (Gyasi, 1987). With the Presidential Special Initiative in Ghana aiming at bringing a total area of 300 000 hectares of land under oil palm cultivation (Toledano et al., 2004) this implies that there is need to find solutions to some of these problems to safe-guard the environment.

### **2.5.3 Oil Palm Growing Areas in Ghana**

The major oil palm cultivation areas in Ghana are concentrated in Eastern, Central, Western and Volta Regions (World Bank/FAO/GOG, 2003). Oil palm is currently, raised on approximately 285,000 hectares of land. Of this nearly 250,000 ha are cultivated by 636,000 small scale farmers and about 35,000ha are under four main private sector production companies, of which about 17,000 ha are managed under nucleus estates, i.e. lands that are owned by the private companies (World Bank/FAO/GOG, 2003). The four companies are: Ghana Oil Palm Development Company (GOPDC), Belgium the largest estate with 18,500ha; Norpalm Plantation (NOPL), Benso Oil Palm Plantation (BOPP) and Twifo Oil Palm Plantation (TOPP) (both owned by UNILEVER) with 14,000ha.

#### 2.5.4 Agro Climatic Requirement

Oil palm requires an average annual rainfall of 2000 mm or more distributed evenly throughout the year and a mean maximum temperature of about 29-33°C and mean minimum temperature of 22-24°C. Also, a sunshine amounting to about 5 hours per day in all months of the year and rising to 7 hours per day in some months are favourable for its growth and development (or solar radiation of around 350cal per cm<sup>2</sup> per day) (Hartley,1988).

#### 2.5.5 Soil

Oil palm can be grown on a wide range of tropical soils. In general, a deep well structured and well drained soil that makes water available within the rooting zone is recommended (Hartley, 1988). In Ghana satisfactory and sustained yields have been obtained on ochrosol-oxisol intergrades over phylites (Brammer,1962). Flat or gentle undulating land is preferred.

#### 2.5.6 Propagation

Oil palm is propagated by seeds. High temperature of 39°C-40°C, adequate supply of oxygen and moisture are required for satisfactory germination. The seeds are normally heat-treated followed by soaking, and air drying before germination. The germinated seeds\* are raised in pre-nursery bags, beds or trays before transferring to larger polythene bags (two-stage nursery) or directly in larger

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\* In this study two different varieties of germinated seeds were obtained from Oil Palm Research Institute-Kade and Ghana Oil Palm Development Company-Kwae, all in the Kwaebibirem District in the Eastern Region of Ghana.

polythene bags (one stage nursery) (Hartley, 1988). The polythene bags may be spaced triangularly at either 70 x 70 x 70cm or 90 x 90x 90cm (GOPDC, 2003). The siting of the nursery should be near a good water source. A minimum of 4.5 litres of water per seedling bag per week is recommended.

### **2.5.7 Pre-nursery and Nursery Establishment**

A wide variety of soils have been successfully used in different countries. These include sandy soil partially sterilised by heating over a fire; deep friable topsoil, overlying alluvial clay mixed with a small proportion of coarse river sand in the proportion 3:2; peat and sand mixed in equal proportions; sandy soil; inland clay-loam topsoil and sifted forest topsoil (Hartley, 1988). In general, fertile topsoil, sufficiently free-draining to prevent 'puddling' or sealing of the surface has been recommended (Hartley, 1988).

### **2.5.8 Nutritional Requirements of Oil Palm**

#### ***(i) Nitrogen (N)***

Nitrogen is an essential major element found in both inorganic and organic forms in the plant, which combines with carbon (C), hydrogen (H), oxygen (O), and sometimes sulphur (S) to form amino acids, amino enzymes, nucleic acids, chlorophyll, alkaloids, and purine bases (Jones et al., 1991). Nitrogen is required for the rapid growth of young oil palm seedlings in the field. The critical value<sup>†</sup> in oil palm leaf is 2.50% (Prevot and Ollangnier, 1954).

To sustain high oil palm yields in intensive and continuous crop production system, nitrogen fertilizer input is required, especially in smallholder and estate

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<sup>†</sup> Critical level is defined as the concentration of the element in the leaf (dry matter basis) above which a yield responses from the element in the fertilizer is unlikely to occur (Prevot and Ollangnier, 1954).

farms in Ghana. Although preferred source of nitrogen recommended for oil palm cultivation is ammonium sulphate, urea, ammonium chloride and ammonium nitrate are also being used (von-Uexkull, 2004). The high cost of nitrogenous fertilizer has led to sub-optimal or no application in the country (Gerken et al., 2001). There is therefore the need to develop alternative cost effective and sustainable nitrogen management systems that can fully exploit organic nitrogen in the various production systems. One way is the recycling of the organic base of the ecosystem. Inclusion of compost as organic fertilizer offers additional benefits such as weed and disease suppression (Hoitink et al., 1993; Boulter et al., 2000), soil erosion control and soil structure amelioration (Gallardo-Lara and Nogales, 1987; Midmore and Jansen, 2003; Agassi et al., 2004; Celik et al., 2004; Zougmore et al., 2004). The organic input can also provide carbon sources to microbial biomass and increase microbial activity (Allievi, et al., 1993) unlike inorganic N fertilizer, and assist in maintaining or increasing soil organic matter status of the soil (Wong et al., 1999; Rivero et al., 2004).

### *Nitrogen deficiency*

Deficiency in nitrogen first shows up as a discolouration of young oil palm fronds, which lose their healthy dark green colour and start to yellow (chlorosis). Also, as the deficiency becomes severe, older leaves start to yellow since nitrogen is mobilised in the older tissues for transport to actively growing portions of the plant. Plants also become weak, stunted and grow very slowly (Hartley, 1988; Jacquemard, 1998).

According to von-Uexkull (2004), deficiency in nitrogen may be caused by a number of factors, which include:

- poor drainage and waterlogged soil;
- infertile soils or soils exhausted by previous agricultural activity;

- failure to properly establish leguminous cover crops (e.g. *Pueraria phaseoloides* and *Centrosema pubescens*) which boost supplies through nitrogen fixation as well as preventing soil erosion; and
- excessive competition from aggressive weeds like the grass *Imperata cylindrica*.

#### *Factors affecting nitrogen uptake*

Oil palm absorbs nitrogen as both nitrate ( $\text{NO}_3^-$ ) anion and ammonium ( $\text{NH}_4^+$ ) cation (Jones et al., 1991).  $\text{NO}_3^-$  generally occurs in higher concentrations than  $\text{NH}_4^+$ , and it is free to move to the roots by mass flow and diffusion. Preference of plants for either  $\text{NO}_3^-$  or  $\text{NH}_4^+$  is determined by the age and the type of plant, soil pH, temperature, and the presence of other ions in the soil solution (Jones et al., 1991; Tisdale et al., 2002). The rate of  $\text{NO}_3^-$  uptake is usually high and is favoured by low pH conditions (Tisdale et al., 2002; Johnston, 2004). On the other hand, plant uptake of  $\text{NH}_4^+$  proceeds best at neutral pH value and is depressed by increasing acidity (Tisdale et al., 2002). Absorption of  $\text{NH}_4^+$  by roots reduces  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  and  $\text{K}^+$  uptake while increasing absorption of  $\text{H}_2\text{PO}_4^-$ ,  $\text{SO}_4^{2-}$ , and  $\text{Cl}^-$  (Tisdale et al., 2002). High levels of  $\text{NH}_4^+$  can retard growth, restrict uptake of  $\text{K}^+$  and produce symptoms of  $\text{K}^+$  deficiency (Tisdale et al., 2002). In contrast, plants tolerate large excesses of  $\text{NO}_3^-$  and accumulate it to comparatively high levels in their tissues. Temperature between 13 °C and 35 °C has also been reported to increase nitrate uptake (Millar, 1965).

#### **(ii) Phosphorus (P)**

Phosphorous is a key component of certain enzymes and proteins, adenosine triphosphate (ATP), ribonucleic acids (RNA), deoxyribonucleic acids (DNA), and

phytin ( Jones, et al.,1991). ATP is involved in various energy transfer reactions, and RNA and DNA are components of genetic information.

Phosphorus specifically promotes root development and is closely involved in the whole reproductive process including fertilisation, seed set and fruit development (Hartley, 1988; Jacquemard, 1998). Phosphorus makes up 0.15% to 1.00% of the dry weight of most crops with sufficiency values from 0.20% to 0.40% in recently mature leaf tissue (Jones et al., 1991). The critical value of phosphorus reported for oil palm leaf is 0.15 % ( Prevot and Ollangnier, 1954). Highest concentration of phosphorus is found in the new leaves and their petioles.

Despite the fact that deficiency of P is acute on the soils of West Africa very little P fertilizers is used by local farmers (Bationo et al.,2003), partially because of the high cost of the imported fertilizers. Superphosphates, single, double or triple (18, 38 and 48 percent  $P_2O_5$ ) are mostly used in Africa and Tropical America (Hartley, 1988). Combined NPK has also been applied to the immature phase of oil palm seedlings (von- Uexkull, 2004).

The use of locally available phosphate rock indigenous in the region (mostly, in Togo-Hahoeto, Senegale-Taiba and Thies, and Ghana) could be an alternative to use of high cost imported P fertilizers. Phosphate rock has been the traditional source of phosphorus that is used in oil palm cultivation in the Far East. It is applied in young seedlings up to year four (Hartley, 1988). The effectiveness of phosphate rock (PR) depends on its chemical and mineralogical composition (Lehr and McClellan, 1972; Chien and Hammond, 1978; Khasawneh and Doll, 1978). The most reactive PRs are those having a molar  $PO_4/CO_3$  ratio less than 5(Bationo et al., 2003). The P concentration of the West African phosphate rocks ranges between 10 to 17% P, and their agronomic potential as judged by molar  $PO_4/ CO_3$  ratio ranges from 4.9 to 23.0 (Ofosu-Budu et al.,2001) .

This indicates that the direct use of most West African PRs as P fertilizer is not agronomically effective. Therefore their effectiveness needs to be improved by suitable amendments. Studies in Zimbabwe on composting PR with cattle manure have shown higher residual effect of composted PR compared to inorganic P fertilizers alone (Dhliwayo,1998). Similarly, Ofosu-Budu et al. (2001) reported on the improvement of the availability of P from mineral and PR through the use of organic sources. The organic residues increased P availability by reducing P sorption and enhancing P solubilisation. Some organic acids (citric and oxalic) produced by certain microorganisms also complex with metals in PR resulting in the release of P (Kpombrekou-A and Tabatabai, 1994).

Composting PRs with agricultural wastes is an age-old, accepted practice to increase solubility of P (Mishra and Banger, 1986; Tander, 1987). However, not all manures are best suited for solubilizing P from PR. Ofosu-Budu et al.(2001) found that there was a low level of dissolution of PR during composting with poultry manure, although the addition of elemental S to the compost enhanced the dissolution of P from North Carolina PR. The low level of PR dissolution in poultry manure was attributed to the high concentration of  $\text{Ca}^{2+}$  in the manure. There is therefore an urgent need to intensify research on enhancing the effectiveness of P from PRs in conjunction with the use of organic inputs.

### *Phosphorus deficiency*

In small oil palm seedlings the oldest leaves become dull and assume a pale olive green colour (Hartley, 1988).The chlorotic condition increases in severity but seedlings do not become fully yellow before necrosis of the tips set in. The necrotic areas are usually of a dark brown colour and in transmitted light the tissue near to these areas are seen to be pale and water-soaked, suggesting rapid cell collapse

(Hartley, 1988). In adult plants frond length, bunch size and trunk diameter are reduced (von- Uexkull, 2004).

*Factors affecting phosphorus retention, availability and uptake*

*pH*:-Several studies illustrated that organic P mineralization increased with increasing soil pH. The pH influence is related to (i) OH<sup>-</sup> competing with HSO<sub>4</sub><sup>-</sup> or HPO<sub>4</sub><sup>2-</sup> for bonding sites,(ii) greater microbial activity at neutral pH levels, and (iii) increased precipitation of Ca-P minerals at pH levels above 7(Tisdale et al.,2002). Soil pH also has a profound influence on the quantity of P adsorption and precipitation in soils. Adsorption of P by Fe and Al oxides declines with increasing pH. Gibbsite [  $\gamma$ -Al (OH)<sub>3</sub> ] adsorbs greatest amount of P at pH 4 to 5. P adsorption by goethite ( $\alpha$ - FeOOH ) decreases steadily between pH 3 and 12 (Tisdale et al.,2002). At low pH values, P retention results largely from reaction with Fe and Al and precipitation as AlPO<sub>4</sub> and FePO<sub>4</sub> oxides. As pH increases, the activity of Fe and Al decreases, which results in lower P adsorption/precipitation and higher P concentration in solution. Above pH 7.0, Ca<sup>2+</sup> can precipitate with P as Ca-P minerals and P availability again decreases (Tisdale et al., 2002).

Phosphorus availability in most soils is at a maximum in the pH range 5.5 to 6.5. As a result phosphate is taken up at a faster rate under such weakly acid condition (Johnston, 2004). Phosphorus is absorbed by plants largely as orthophosphate ions (H<sub>2</sub>PO<sub>4</sub><sup>-</sup> and HPO<sub>4</sub><sup>2-</sup>),which are present in soil solution. The amount of each form present depends on soil solution pH. At pH 7.2 there are approximately equal amounts of H<sub>2</sub>PO<sub>4</sub><sup>-</sup> and HPO<sub>4</sub><sup>2-</sup>. Below this pH, H<sub>2</sub>PO<sub>4</sub><sup>-</sup> is the major form in soil solution, whereas HPO<sub>4</sub><sup>2-</sup> is the predominant form above pH 7.2. Plant uptake of HPO<sub>4</sub><sup>2-</sup> is much slower than with H<sub>2</sub>PO<sub>4</sub><sup>-</sup>(Tisdale et al., 2002; Johnston, 2004)

*Organic matter*:- Organic compounds in soils increased P availability by (1) the formation of organophosphate complexes that are more easily assimilated by plants, (2) anion replacement of  $\text{H}_2\text{PO}_4^-$  on adsorption sites, and (3) the coating of Fe and Al particles by humus to form a protective cover and thus reduce P adsorption (Tisdale et al., 2002). Organic anions produced from the decomposition of organic matter may also form stable complexes with Fe and Al, thus preventing their reaction with  $\text{H}_2\text{PO}_4^-$ . These complex ions also may release P previously fixed by Fe and Al by the same mechanism. The anions that are most effective in replacing  $\text{H}_2\text{PO}_4^-$  are citrate, oxalate, tartrate, malate, and malonate, which occur as organic matter degradation products (Tisdale et al., 2002).

*C/P ratio*:-In most soils, total organic P is highly correlated with soil organic carbon. The quantity of organic P in soils generally increases with increasing organic C and or N (Tisdale et al.,2002).Thus mineralization increases with increasing total organic P. The C/P ratio of the decomposing residues regulates the predominance of P mineralization /immobilization. As the ratio of soil organic C/P increases (i.e. decreasing organic P), P immobilization increases and vice versa.

*Temperature*:- The rate of most chemical and biological reactions increases with increasing temperature up to a limit. Mineralization of P from soil organic matter or crop residues is dependent on soil biological activity, and increases in temperature stimulate biological activity up to the optima for the predominant biological systems. Results of most studies also showed that P adsorption generally increases with higher temperatures (Tisdale et al., 2002).

*Interaction of N with P*:- Since N accounts for at least one-half of the total number of ions absorbed, it is reasonable that P uptake is influenced by the presence of fertilizer N. N promotes P uptake by plants by (1) increasing top and root growth, (2) altering plant metabolism, and (3) increasing the solubility and availability of P

(Tisdale et al.,2002). Increased root mass is largely responsible for increased crop uptake of P. Ammonical fertilizers have a greater stimulating effect on absorption than  $\text{NO}_3^-$ . The ratios of 3 to 1 between N and P, and 200 to 1 between P and Zn are considered critical. The ratio of N to P is used as DRIS norm (Jones et al., 1991).

*Soil moisture:* Moisture content of the soil influences the effectiveness and availability of applied P in various forms. When the soil water content is at field capacity, 50 to 80% of the water soluble P can be expected to move out of the fertilizer granule within a 24-hour period. Even in soils with only 2 to 4% moisture, 20-50% of the water- soluble P will move out of the granule within the same time (Tisdale et al.,2002).

### **(iii)Potassium**

Potassium is commonly required in young oil palm seedlings and in adults. Where required, applications of K have been shown to bring palms earlier into bearing. It also reduces the incidence of leaf diseases such as *Cercospora elaeides* in young palms (Hartley, 1988). Oil palm carries large quantities of potassium particularly in the stalks, fibres and shells, and therefore correspondingly large amounts are removed at harvest. Potassium has a crucial role in oil palm metabolism with a direct effect on the functioning of the chlorophyll molecule in photosynthesis (i.e. it is required in the accumulation and translocation of newly formed carbohydrates). In addition, potassium ions maintain the water status of the plant and turgor pressure of its cell, the opening and closing of the stomata. Therefore the controlled entry of carbon dioxide for photosynthesis, and the controlled loss of water. For this reason, the potassium ion is commonly called the 'gatekeeper' and it plays a key role in tolerance to drought and the effects of wilt disease caused by fungal pathogens such as *Fusarium oxysporum var elaeidis*.

Potassium comprises of 1.00% to 5.00% of the dry weight of leaf tissue with sufficiency values from 1.50% to 3.00% in recently mature leaf tissue for many crops (Jones et al., 1991). In oil palm potassium content is considered deficient when K critical values are less than 1.0% (Prevot and Ollangnier, 1954). Highest concentrations are found in new leaves, their petioles, and plant stems.

Potassium exists in the soil in four forms: as the  $K^+$  ion in the soil solution, as exchangeable K on soil colloids, as K fixed in the lattice of 2:1 clays, and as a component in K-bearing minerals. Equilibrium exists among the K in the soil solution, exchangeable K, and fixed K. When K fertilizer is applied to soil solution, the equilibrium shifts toward the exchangeable and fixed K; a shift, which is reversed as K, is removed from the soil solution by root absorption.

### *Potassium deficiency*

In very young seedlings in sand culture, leaves begin to show a pale green to white interveinal mottling with minute white or yellowish rectangular spots. Later the leaves become pale olive or ochre in colour and the tips and margins become necrosed, the necrosis being typically pale grey or silvery (Hartley, 1988). In larger seedlings the chlorosis is similar, being interveinal with the veins and adjacent tissues remaining a normal green colour. Necrosis of the leaflet tips and margins also proceeds in the same manner as in smaller seedlings, the transition zone between the chlorosed and necrotic tissue being very thin and pale brown. Minute clear spots also appear scattered over the laminae (Hartley, 1988). These symptoms are accompanied or followed by marked shortening of the rachis and of the leaflets and this gives the leaf a 'bunchy' appearance, but these symptoms do not necessarily persist in later formed leaves (Hartley, 1988). Other symptoms associated with potassium

deficiency in mature oil palm include ,confluent orange spotting (Bull,1954a), mid crown yellowing (Chapas and Bull,1956), and Mbawsi symptoms (WAIFOR,1956).

*Confluent orange spotting*:-is the name used to describe a condition in which chlorotic spots, changing from pale green through yellow to orange, develop and enlarge both between and across the leaflet veins and fuse to form compound lesions of a bright orange colour (Hartley, 1988). Under a lens a pale yellow halo can be seen around the spot, but to the naked eye the boundary between spot green leaf appears sharp. Necrosis within spots is common but irregular, and may be accompanied by fungus invasion which is secondary. Orange Spotting described in Malaysia and Sumatra is virtually identical except that in Malaysia the orange spots tend to be more elongated (Hartley ,1988), a tendency not unknown in Africa.

*Mid -crown yellowing*:- Leaves around the tenth position on the phyllotaxis become pale in colour and terminal and marginal necrosis follows. A band along the midrib usually remains green. There is a tendency for later-formed leaves to be shorter and the palm has an unthrifty appearances with much premature withering, sometimes referred to as 'grey withering' of older leaves.

*Mbawsi symptoms*:-Large yellow or orange patches appear on affected leaflets. The midrib and a narrow strip on either side of the midrib remain green. The orange patches usually contain a mass of minute orange spots showing little or no necrosis.

The cause of potassium deficiency is inadequate soil concentration, which is a perpetual problem in tropical soils exhausted by continual cropping and heavy rainfall. In oil palm K is usually applied as the chloride (containing the equivalent to 60-62 percent  $K_2O$ ) or sulphate (48-52 per cent  $K_2O$ ) according to availability and price (Hartley, 1988).It is in line with this that the use of compost made with cocoa pod husk is being research on in this study. Ahenkorah et al. (1981) compared the K

nutrient value of cocoa pod husk with inorganic muriate of potash and observed that there were no significant difference between the cocoa pod ash (3.8%) and muriate as source of K for maize. Potassium is sometimes not required where there is a strong P or Mg deficiency and in the latter case its application can produce or increase intense orange frond (von- Uexkull, 2004). Antagonisms are common, the most important being between K and Mg.

#### *Factors affecting potassium uptake*

Rubaeka et al. (1998) reported that the availability of K, Mg, Cu and Zn declines above pH 7. High K concentrations first result in Mg deficiency and, when K is in greater imbalance, will cause Ca deficiency. The K to Mg and K to Ca ratios are used as DRIS norms. Ammonium ( $\text{NH}_4^+$ ) can also play a role in the balance that exists among the three cations, K, Ca and Mg.

#### *(iv) Calcium*

Calcium is important for root development and meristem (the growing point) activity but deficiencies have never been documented. Calcium content in plants ranges between 0.20% to 3.00% percent of the dry weight in leaf tissues, with sufficiency values from 0.30% to 1.00% in leaf tissues of most crops (Jones et al., 1991). Calcium exists as the  $\text{Ca}^{+2}$  cation in the soil solution and as exchangeable Ca on soil colloids. Usually Ca is the cation of highest concentration in the soil in both soluble and exchangeable forms for soil high in pH (>8.0), which may contain sizable quantities of Ca as either precipitates of calcium carbonate and calcium sulphate.

#### *Factors affecting calcium uptake*

The relationship between Ca and K is well known, as is the relationship between Ca and Mg; these ratios are used as DRIS norms. The ratio of Ca to N in

fruit crops and a similar ratio between Ca and B may be related to quality. Ammonium nutrition can create a Ca deficiency by reducing its uptake.

#### **(v) Magnesium**

Magnesium forms the framework of the chlorophyll molecule and any deficiency is seen long before yield begins to suffer. Symptoms are a yellowing of leaflets of older fronds. The yellowing of the leaflets is most acute and obvious at the margins of the plot where leaves are exposed to most sunshine (von- Uexkull, 2004). Magnesium deficiency is a frequent problem in light textured soils and in acid soils where the top soil has been eroded (von- Uexkull, 2004). Magnesium deficiency is much common in replanting than new plantings (Chan and Rajaratrion, 1977). Magnesium exists as  $Mg^{+2}$  cations in the soil solution and as exchangeable Mg on soil colloids. Magnesium is usually applied as hydrated magnesium sulphate (Epson salts, 46-48% per cent  $MgSO_4$  or 16 per cent MgO); crude magnesium sulphate (Kieserite, 26 percent  $MgSO_4$ , 30-32 per cent MgO). Magnesium limestone is not usually suitable owing to the K/Ca and Ca/Mg antagonisms, but may be useful where magnesium is required in very acid conditions as on the Malaysian acid sulphate soils. Magnesium chloride has been used quite extensively in Sumatra and Equador and has been especially advocated where a chlorine deficiency is also suspected (Hartley, 1988).

#### **2.5.9 Nutritional Requirement of Young Oil Palm Seedlings at the Pre-nursey and Nursery**

From the point of view of nutrient budget for the crop at various growth stages, oil palm shows a sharp rise in its uptake of major nutrients, particularly K and N, from the second year after planting (Hartley, 1988). This uptake levels off after 5-

6 years of growth. It is thus of critical importance to provide adequate nutrition while the palms are immature, if early harvests are to be large and rapid increase in yields to be sustained. Nutrients can be reintroduced into the oil palm ecosystem by measured inorganic or organic fertilizer application based on requirement as determined by soil testing and foliar analysis. In a single stage poly bag nursery the first 3-4 months correspond with the pre-nursery stage. No fertilizer is supplied at this stage. However, in polybags nurseries in the Far East monthly application of a compound fertilizer of formula N12: P12: K17: Mg 2 is recommended starting about 1 month after transplanting from a pre-nursery and increasing the rate per plant from 5g at 1 month to 10g at 2-4 months, 20g at 5-6 month and 30g at 2-9 months (Hartley, 1988). Similarly, from one to three-leaf stages (i.e. from the end of the second month till the end of the third month), urea can be watered on weekly basis at the rate of about 7g in 5 litres of water per 100 seedlings (Hartley, 1988). The same author reported that this rate may be doubled at the four to five leaf stages, and solid fertilisers can then be applied from about the end of the fourth month. The recommended monthly application starts with about 10g per plant and gradually increases to the rate of about 30g at 10 months. GOPDC also starts fertigation one-month after planting. The company dissolves 100g of N12: P12:K12:Mg 2 in 10 litres of water and applies to thousand seedlings fortnightly (personal contact). Also, solid fertilizer is applied to seedlings from the fourth month at the rate of 5g per plant. This rate is cumulatively added up every month to 80g per plant at the end of the nursery period i.e., 12 months from planting. Conversely, Tuner and Gillbanks, (1974) recommended solid application of N 15:P 15:K 6: Mg 4 mixture to start at 2 months at the rate of 1g, increasing to 5g at 3-4 months but he cautioned that care should be taken in order not to cause leaf scorch.

Application of conventional inorganic fertilizers in oil palm nurseries and newly established plantations remains labour intensive and is difficult to supervise as the frequency of fertilizer application can range from 12 to 26 applications per annum. Secondly, high prices of mineral fertilizers as a result of the removal of subsidy and poor distribution network cause fertilizer use in Ghana to be low (Gerken et al., 2001). There is therefore the need to explore the possibility of using compost as a means to reducing inorganic fertilizer frequency. In Nigeria, Aya (1969 and 1971) reported satisfactory growth by mixing the nursery soil with cattle manure and using the same fertilizer schedule as for field nurseries. Sunitha and Varghese (1999) reported that nutrient demand in palm plantations may be met by adopting an integrated approach of nutrient management i.e. using both compost and inorganic fertilizer. The recycling of agro-wastes like palm wastes reduce the need for chemical fertilizer in mature oil palm plantations by restoring some of the potassium and nitrogen removed with the harvested crop (Hartley, 1988).

## CHAPTER 3: METHODOLOGY

### 3.1 DESCRIPTION OF THE STUDY AREA

#### 3.1.1 Geographical Location

The study was carried out at the University of Ghana Agricultural Research Station, Okumaning near Kade in the Kwaebibirem District ( $6^{\circ} 05' N$ ;  $0^{\circ} 05' W$ ) 175 Km from Accra. The Station is about 150 m above sea level. It is located in the Moist Semi - Deciduous vegetation zone in the Eastern Region of Ghana (Figure 3.1 and 3.2).

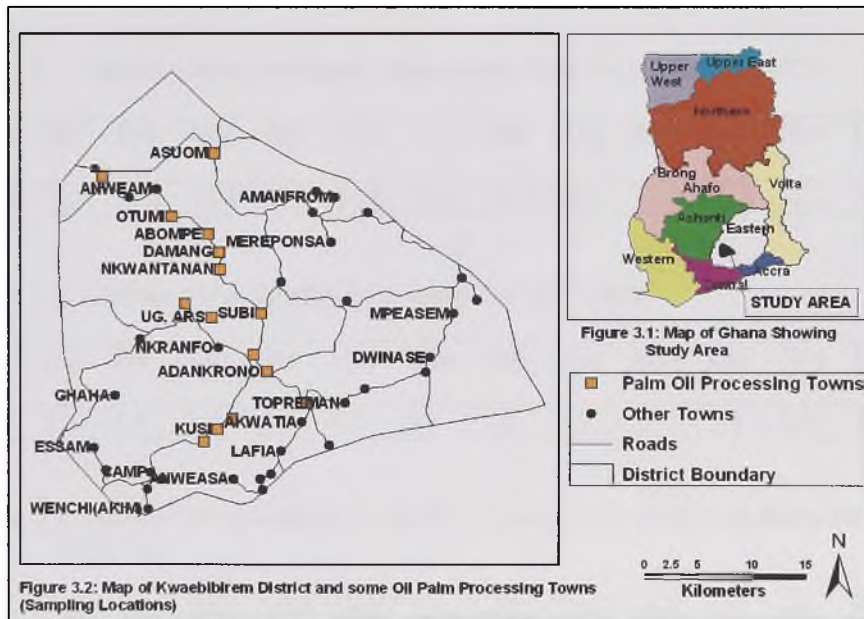
#### 3.1.2 Relief and Drainage

The Birim River is the major river that drains through the district. It takes its source from the Atewa range of hills in the Eastern Region of Ghana and follows a course of 175 km to join the river Pra. The Birim basin located between latitude  $0^{\circ} 20' W$ ,  $1^{\circ} 15' W$  and longitude  $5^{\circ} 45' N$ ,  $6^{\circ} 35' N$  has an estimated area of 3,875 km<sup>2</sup> with seven important tributaries. They are, Adim, Apeam, Kadewa, Meremping, Osenase, Si, and Supong rivers. The meandering river course is generally sheltered and fringed by gallery forest with trailing vegetation in some portions. The river Birim (from Kade downstream) and some of its tributaries e.g. Asubone, Supong, Ablasika and Adenkyensu might contain diamond. The bed of the streams consists of sand, gravels, rocks and are generally muddy with decaying vegetable matter (Ansa-Asare and Asante, 2000).

#### 3.1.3 Geology and Soil

The soils of the area according to Owusu-Bennoah et al. (2000) are generally developed from rocks of the Birrimian system (middle-Pre-Cambrian) which consist

mainly of argillaceous sediments metamorphosed into phyllite. The well-drained upland soils belong to the forest Ochrosol Great Soil Group of the Ghanaian soil classification system (Brammer, 1962) and are generally classified as Acrisols in the FAO-Unesco Revised Legend (FAO, 1988) and as Ultisols in Soil Taxonomy (Soil Survey Staff, 1998). The soils are well drained, rich in iron oxides, strongly leached with pH (CaCl<sub>2</sub>) of 3.7-4.4 in the subsoil but the ion-pump maintains relatively high pH (CaCl<sub>2</sub>) 5.4-5.9 and base saturation in the top soil.



*Source: Survey Department ; Composed by Albert Allotey, Remote Sensing & GIS Laboratory, Department Of Geography and Resource Development, University of Ghana, Legon*

### 3.1.4 Climatic Condition

The climate of the area is humid tropical. The monthly average temperature reaches a Maximum of 28-29°C in February and March, and a minimum of 25-26 °C in July /August .The rainfall pattern is bimodal with peaks (150-200mm) in May/ June and September/October. The potential evapotranspiration varies between 3mm daily in the rainy season and 5mm in the dry season, and may reach an annual value of 1400mm. The soil temperature regime is isohyperthermic and the soil moisture regime is udic (Soil Survey Staff, 1998).

Table 3. 1: Monthly Mean Maximum Temperature from Jan to Dec 2003 (°C)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
2003	32.2	34.1	34.8	33.3	33.3	30.9	30.4	29.2	31.1	32.5	32.3	31.6

Table 3.2: Monthly Mean Rainfall from Jan to Dec 2003 (mm)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
2003	1.2	1.8	2.4	5.4	4.7	6.5	1.0	3.2	2.1	5.8	4.2	1.0

Table 3.3: Monthly Mean Relative Humidity Values at 1500 GMT from Jan to Dec 2003 (%)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
2003	57.9	54.9	54.1	63.0	62.1	70.4	66.0	71.3	76.1	65.3	68.4	61.5

*Source: University of Ghana Agricultural Research Station, Kade Campus*

### 3.1.5 Human and Economic Activities

Demographically, Kwaebibirem district is the fourth densely populated district in Eastern Region with a total population of 179,209 according to the 2000

census (GSS, 2002). This figure/population represents 0.95% of the total population of Ghana. The inhabitants are mainly farmers who grow cash crops such as oil palm (*Elaeis guineensis*), citrus (*Citrus spp*) , cocoa(*Theobroma cacao*), food crops such as rice (*Oryza sativa*), maize(*Zea mays*), cassava (*Manihot utilissima* ) and plantain (*Musa sapientum*). Diamond is the major mineral in the area that is actively mined. However gold is also won. Timber and lumber are also extracted from the forests in the basin. Palm oil processing is the major occupation of significant number of the women.

## 3.2 METHODOLOGY

### 3.2.1 Quantity of Waste Generated, Perception and Willingness of Palm Oil Processing Mills and the Public to Recycle and Use Compost

A Survey was conducted to identify;

- oil processing Mills in the district
- types and amounts of residues generated
- knowledge base of the women who are polluting the environment by their activities
- perception of managers and workers of the Mills to compost residues
- the willingness of local farmers, urban vegetable growers and floriculturists to use compost

This was done through interviews in the local language of inhabitants and through the administration of questionnaires also translated into the local language by the investigator. Two different forms of questionnaire were administered one to the oil processing Mills in the Kwaebibirem district and the other to the potential compost users at both Kwaebibirem district and Accra metropolis\*.



Plate 3.1: Interviewing Oil Mill Workers

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\* See appendix for copies of the questionnaires. In all 200 questionnaires were administered.

### 3.2.2 Determination of the Chemical Composition of the Palm Oil Mill Effluent (POME)

Samples of POME were taken in July 2004. Two litres of POME per site were taken from six different locations (Okumaning, Kusi, Damang, Subi, Adonkrono and Kwae) representing POME sources for small scale operation . For GOPDC the samples were taken from treatment ponds and since the remaining Mills did not have treatment ponds, samples were taken from gutters nearby at interval of one month for two months and the chemical characteristics of the POME were determined. The criteria for selecting the Mills were based on the nearness of the Mills (between 50 to 100m ) to water bodies and their processing capacity (metric tonnes of fresh fruit bunch per hour).The parameters that were measured included pH, electrical conductivity, suspended solids, total solids, total dissolved solids, chemical oxygen demand, biological oxygen demand and oil.

#### (i) *pH*

pH is the  $-\log[H^+]$  and denotes the activity of protons in solution (like that of POME). In this study the principle and procedure of APHA, AWWA, WEF,( 1998) was followed.

#### *Procedure*

The pH meter was calibrated using pH 4 and 7 buffers. After that the various POME samples were then measured by dipping the electrode into the solution and the corresponding pH values recorded. The electrode after measuring a sample was rinsed with deionised water and shaken before inserting into another samples.

(ii) *Electrical Conductivity*

Electrical Conductivity is the ability of a substance to conduct electricity. This depends on the ionic strength of the sample. The determination of the electrical conductivity provides a rapid and convenient way of estimating the concentration of electrolytes in solution.

*Procedure*

Electrical conductivity of the samples was determined according to the procedure described by APHA, AWWA, WPCF, (1995) with a conductivity meter (JENWAY model 4020). The instrument was calibrated with standard KCl (0.01M solution), which has a conductivity of 1413 $\mu$ S/cm at 25°C. The conductivity cell and the beakers were thoroughly washed with a portion of the sample that was examined. The cell was then inserted into the sample and the value (conductivity) on the meter was recorded. This was repeated for the various samples. Ordinary thermometer was used to measure the temperature of the samples,

*Calculations*

Conductivity at 25°C was calculated as follows:

$$K = \frac{K_m}{C}$$

$$(1 + 0.0191)(T - 25)$$

where  $K_m$  = measured conductivity,  $\mu$ S/cm at 25°C

$C$  = cell constant,  $\text{cm}^{-1}$

$T$  = temperature of sample

The results were expressed in  $\mu$ S/cm recorded to two decimal places for low readings and one decimal place for values above 2.0 $\mu$ /cm.

### **(iii) *Suspended Solids***

Suspended solids (SS) are the solids retained by a filter of 2.0  $\mu\text{m}$  (or smaller) pore size under specific conditions. This analytical procedure describes the method for the determination of suspended solids that involves the filtration and drying at 105°C /180°C.

#### *Procedure*

The membrane filtration method described by APHA; AWWA; WPCF (1995) was used. Suction began after the filtration apparatus was assembled. The filter was moistened with 10ml of deionised water to seat it. The sample bottle was shaken vigorously and 50ml of the sample was rapidly transferred into the funnel. The filter was washed thoroughly three times with 10ml volumes of distilled water. After the water was allowed to drain the filter was removed from the filter holder and placed into a weighing dish which was then dried at 105°C for one hour. The sample was allowed to cool in a desiccator and weighed. Drying was repeated until a constant weight was obtained. The analysis procedure was repeated using 500ml of control standard<sup>†</sup>.

#### *Calculations*

Total suspended solids (mg/l) =  $(A-B) \times 10^6 / C$

where A= weight of filter + dish + residue, (g)

B= weight of filter + dish, (g)

C= volume of sample filtered (ml).

Suspended solids results less than 10mg/l were reported to 1 decimal place and those greater than 10mg/l to the nearest whole number.

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<sup>†</sup> Control standard concentration was 4mg/l. It was made up of 20mg/ of microcrystalline cellulose and 20 mg of Kaoli to 10 litres deionised water.

**(iv) Total dissolved solids (TDS) (Gravimetric method)**

Total dissolved solids (TDS) are the portion of total solids that pass through a standard filter paper of 2.0µm (or smaller) nominal pore size. Water with high TDS generally is of inferior palatability.

*Procedure*

The Total Dissolved Solids (TDS) were determined by gravimetric method as described by APHA; AWWA; WPCF (1995). The sample was vigorously shaken and by means of a 100ml graduated cylinder 50 ml of the sample was transferred into the funnel. The sample was filtered and a vacuum was applied for about three minutes to ensure that as much water was removed as possible. The fibre filter was washed with three 10ml volumes of deionised water whilst suction continued for three minutes. The total filtrate (with washing) was transferred to a weighed evaporating dish and evaporated to dryness on a water bath. The evaporated sample was dried for at least 1 hour at 105°C. After drying the sample was cooled in a desiccator and weighed to constant weight. The procedure was repeated for the various samples.

*Calculations*

$$\text{Total dissolved solids (mg/l)} = (A-B) / C \times 10^6$$

where A= weight of dried residue and dish, g

B= weight of dish, g

C= volume of sample, ml

The results were expressed as total dissolved solids dried at 105°C, mg/l to the nearest 0.1mg/l.

(v) **Biochemical Oxygen Demand (BOD)**

*Procedure*

The azide modification of the Winkler method (APHA, AWWA, WEF., 1998) was used in the determination of BOD. The samples were diluted by adding dilution water. Six hundred millilitres (600ml) of the diluted sample was prepared with a dilution factor that could yield a residual dissolved oxygen (DO) of at least 1mg/l and a DO uptake of at least 2mg/l after 5 days incubation. The DO uptake in this range yields the most reliable results. Two 300ml BOD bottles were filled with the diluted sample. One of the two bottles was then incubated in the dark at 20°C for a period of 5 days. The oxygen in this other bottle was fixed by adding 2ml MnSO<sub>4</sub>, followed by 2ml alkaline-iodine-azide and corked carefully to exclude air bubble escaping. The content of the bottle was then shaken thoroughly by inverting several times and then the precipitate was allowed to settle at the bottom of the sample. After the precipitate had settled, 2ml conc. H<sub>2</sub>SO<sub>4</sub> was added, corked and the bottle again shaken several times to dissolve the precipitate giving an intense yellow colour. 100ml of the sample was then titrated with m/80 sodium thiosulphate to a pale yellow colour and 1ml starch solution was added as indicator. Titration was continued to the first disappearance of the blue colour. The same procedure was followed for the incubated sample at the end of the 5 days to ascertain the difference in DO for the calculation of the BOD.

*Calculation*

$$\text{BOD}_5 \text{ mg/l} = (D_1 - D_2) / P$$

where  $D_1$  = DO of diluted sample immediately after preparation

$D_2$  = DO of diluted sample after 5 days incubation at 20°C

$P$  = Decimal volume fraction of sample used.

DO is dissolved oxygen. The amount of DO in the sample was calculated as follows:

$$\text{Mg/l O}_2 = \frac{\text{volume of M/80 thiosulphate}}{\text{volume of sample used}}$$

(vi) **Chemical Oxygen Demand (COD)**

The chemical oxygen demand (COD) is the amount of oxygen consumed by organic matter after boiling the sample in an acid potassium dichromate solution. The quantity of oxidant consumed is expressed in terms of its oxygen equivalence.

*Procedure*

The open reflux method using potassium dichromate and ferrous ammonium sulphate was used (APHA;AWWA;WPCF,1995). Five millilitres (5ml) of each of the samples was placed into a labelled culture tube and 3ml of potassium dichromate solution and 7ml of H<sub>2</sub>SO<sub>4</sub> reagent were added, respectively, to it. The tubes were capped tightly and shaken to mix thoroughly. The tubes were then placed in a digester and refluxed for 2 hours. After the digestion, the samples were cooled to room temperature and 1 to 2 drops of ferroin indicator added. The samples were then titrated against standard Ferrous Ammonium sulphate (FAS) solution. The colour change observed was blue-green to reddish brown or wine (end point) precipitate. A blank, containing the reagents and a volume of deionised water equal to that of the samples was refluxed and titrated in the same manner. The COD in mg/l was then calculated for the samples as follows:

$$\text{COD as mg O}_2/\text{l} = \frac{(A-B) \times M \times 800}{\text{ml sample}}$$

where A = ml FAS used for blank

B = ml FAS used for sample

M = molarity of FAS and

8000 = milliequivalent weight of oxygen 1000 ml/l.

**(vii) Oil and Grease**

The extraction method using petroleum was used (APHA, AWWA, WEF, 1998).

*Procedure*

Two hundred (200ml) of the sample was taken and acidified with hydrochloric acid to pH 2 and transferred to a separation funnel. The sampling bottle was then rinsed with 30ml petroleum ether and poured to a separation funnel. The content of the separation funnel was corked and shaken for 2 minutes. Afterwards it was inverted and the pressure released from it through the bottom. This was repeated until there was no more pressure build up in the separating funnel. The separation funnel was hung upright with the help of retort stand. It was then opened to allow solvent to separate from the water sample. After the layer had separated, the solvent layer was drained through a funnel containing solvent moistened filter paper into a clean-tared distillation flask. The solvent was then distilled from the distillation flask on a water bath at 70° C till the flask was dry. It was then cooled in a dessicator for 30 minutes and weighed.

*Calculation*

$$\text{Mg oil and grease / l} = \frac{(A-B) \times 1000 \times 1000}{\text{ml sample}}$$

where A = total gain in the weight of the flask in grams

B = solvent blank.

The result was expressed in mg/l oil.

### 3.2.3 Building of Compost Piles

The EFB was first cut into pieces before use. This was to allow efficient aeration (aerobic composting), and to ensure that the microbes, fungi and actinomycetes present in the residues easily decompose the EFB. The cut EFB, MF, PKC and POME were mixed at different combinations (Table 3.4) with, and without cocoa pod husks, poultry droppings and rock phosphate . The mixture of the residues was heaped in boxes (of sizes 1m<sup>3</sup>) and covered with plastic sheet to prevent soaking from rains since the whole process was carried out in the open space. Moisture initially was adjusted to 65%. In all, twelve different experimental treatments were obtained, each in duplicate.

Table 3. 4: Different Combinations of Raw Material used in Composting

Sample	Raw materials used in composting	Volume ratio
CA	EFB + POME	1 : 1
CB	EFB + PKC + CH + WATER	1 : 1 : 1 : 1
CC	EFB + POME + MF	1 : 1 : 1
CD	EFB + PKC + WATER	1 : 1 : 1
CE	EFB + PKC + CH + POME	1 : 1 : 1 : 1
CG	EFB + PKC + CH + PD + WATER	1 : 1 : 1 : 1
CH	EFB + PKC + CH + PD + POME	1 : 1 : 1 : 1 : 1
CI	EFB + PKC + RP + POME	1 : 1 : 1 : 1
CJ	EFB + RP + POME	1 : 1 : 1
CK	EFB + PKC + RP + CH + POME	1 : 1 : 1 : 1 : 1
CL	EFB + PKC + POME	1 : 1 : 1
CM	EFB + WATER	1 : 1



Plate 3.2: Building Compost Piles in Boxes    Plate3.3: PVC Pipe<sup>‡</sup> Inserted into Pile to



Plate 3.4: Matured Compost under Storage

### 3.2.4 Determination of Maturity Indices

The indices used in this study to establish the maturity of the compost included pH, humus colour, temperature, carbon dioxide, C/N ratio and germination index.

#### (i) *pH*

Compost samples were taken, air-dried and ground to pass through a two millimetres (2mm) sieve. Ten grams (10g) of each of the ground samples was taken into a 50ml beaker, where 20 mls of distilled water was added. The suspension was stirred several times with a glass rod for 10 minutes after which it was allowed to

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<sup>‡</sup> Temperature of the piles was monitored through the pipes using a thermometer

stand for 30 minutes. Buffer solutions of pH 4 and 7 were used to calibrate the pH meter. The electrode of the pH meter was then inserted into the partly settled suspension (supernatant) and the pH for the various compost treatments were measured one after the other.

**(ii) Temperature**

PVC pipes (diameter 6 cm) with holes drilled along and around them were inserted into the various compost piles from the beginning of the composting process. Thermometers were inserted into the PVC pipes at 60cm depth and the various daily temperatures of the compost piles were recorded between 7:00 and 7:30am for sixteen weeks. The mean weekly temperature for a particular compost pile was calculated by adding all the daily temperatures divided by the number of days in a week.

**(iii) Carbon dioxide evolution rates or microbial respiration**

Microbial respiration in compost is used as an indicator to determine compost maturity. High respiration value indicates that compost is immature and vice versa. In this study the principle and procedure given by Black, (1965) was used. NaOH of concentration (0.1M) was placed in an open jar along side with compost in another open jar. The compost together with the NaOH was then covered with a glass cylinder that is closed at the upper end. As carbon dioxide evolves from the compost, it is trapped in the cylinder and is confined until it is absorbed by the alkali. After 24hrs, the alkali was removed and the unreacted portion was determined by titrating against 0.1M HCl. By means of subtraction, the amount of CO<sub>2</sub> that combined with the alkali was determined as shown below.

$$\text{Milligram of CO}_2 \text{ evolved per day} = \frac{(B-V) NE}{\text{weight of sample}}$$

where  $B$  = volume (millilitres) of acid needed to titrate the NaOH in the blank jar to the end point.

$V$  = volume (millilitres) of acid that was needed to titrate the NaOH in the jars exposed to the compost.

$M$  = Molarity of the acid used

$E$  = Equivalent weight of carbon or carbon dioxide

To express the data in terms of carbon,  $E=6$ ; to express in terms of  $\text{CO}_2$ ,  $E = 22$



Plate 3.5: Laboratory Determination of Carbon Dioxide Evolution from Compost Samples

**(iv) Determination of C:N**

Carbon was determined by dry combustion in a C-analyzer model CS 500. About 0.0005mg of compost or 0.001mg of soil was put into the analyzer at a temperature of 1200K and value of carbon recorded in percentage. The Kjeldahl method already described was used to determine nitrogen. The C/N ratio for each treatment was then estimated by dividing carbon by the total nitrogen.

(v) ***Germination index***

The germination experiment to determine compost maturity is based on the principle that immature compost contains phytotoxins that inhibit germination of seeds (Zucconi et al., 1981a; Innanotti et al., 1993; Tiquia et al., 1996). In determining germination index *Lepidium* seeds were recommended by Innanotti et al. (1993) because of their earliness in germination but this is not common in developing countries like Ghana. Therefore tomato seeds were used in this experiment because they also germinate early (within three days) and were found to have a wider range of tolerance to ammonia, copper, zinc toxicity compared to other species such as cabbage, cucumber, spinach, onion and kale (Tiquia et al., 1996). The various compost treatments were sampled, air-dried and passed through 2.0mm sieve. Twenty (20) grams each of the samples were taken into a bottle and shaken with 50mls of distilled water for one hour. The various solutions were filtered with Whatman paper No. 42. Using three replicates per extract, 50mm petri dishes were lined with filter papers and twenty viable tomato seeds were placed in each petri dish. The dishes were labeled according to the treatments. Two millilitres of filtrate was pipette into each of the corresponding petri- dishes. This was repeated for the remaining replicates. For the control, distilled water was used. The treated seeds were kept under ambient conditions in the laboratory and temperatures monitored. Three days after treatment, the experiment was stopped because there was extensive germination in the control petri- dishes. Germination was stopped by adding 1ml 50% ethanol to each of dishes. Treatments were evaluated by counting the number of germinated seeds and measuring the length of the roots (radicle). Seeds that failed to germinate were regarded to have zero root length. Germination index was calculated

by multiplying germination and root growth, both expressed in percent values (root growth in % of control) Zucconi et al. (1981b).

$$\text{Germination index} = \frac{\text{mean germination in compost extract} \times \text{mean root length in compost extract}}{\text{mean germination in distilled water} \times \text{mean root length in distilled water}} \times 100$$

Compost is considered matured when the germination index is above 100%.



Plate3.6: Determination of Germination and Root Growth of Tomato Seeds

### 3.2.5 Compost, Soil and Plant Analysis

#### *(i) Nitrogen*

##### *Procedure*

The modified Kjeldahl method as described by Black, (1965) was used to determine total N in plant, compost or soil samples. The samples were air dried, ground and passed through 2mm sieve, after which 0.1g of each of the samples were weighed into 500ml Kjeldahl flask and heated with 5ml of concentrated H<sub>2</sub>SO<sub>4</sub> in the presence of selenium catalyst and salts (Na<sub>2</sub> SO<sub>4</sub>) The resulting digest was distilled with excess strong alkali (NaOH) and condensed as ammonium hydroxide

( $\text{NH}_4\text{OH}$ ) to liberate ammonia. The liberated ammonium was trapped in 5ml of 2% boric acid and was titrated against 0.01M HCl using mixed indicator (bromocresol green and methyl red) until the solution changed from green to reddish end point. The percentage nitrogen was calculated as shown below.

$$\%N \text{ in plant sample} = \frac{(\text{Titre value}) 0.2 \times v \times 100}{w \times al \times 1000}$$

$$\%N \text{ in compost sample} = \frac{(\text{Titre value}) \times 0.01 \times 14 \times v \times 100}{w \times al \times 1000}$$

Titre value = volume of the titre HCl for the sample

v = final volume of the digestion = 50ml

w = weight of the sample taken in grams = 0.1g

al = aliquot of the solution taken for analysis = 5ml

0.01 = Molarity or Normality of HCl

14 = Molar weight of nitrogen

**(ii) *Determination of ammonium nitrogen ( $\text{NH}_4^+\text{-N}$ ) and nitrate nitrogen ( $\text{NO}_3^- \text{N}$ ) in compost and soil***

***Procedure***

One gram (1g) of air-dried ground compost sample that has passed through 2.0 mm sieve was weighed into a 200ml plastic bottle, and 40ml of 2MKCl extracting solution was added. The bottle was covered and the content shaken for one hour. The sample was then centrifuged and filtered through No. 5 or No. 42 Whatman filter paper.

### *Steam Distillation*

First the steam distillation apparatus was set up by using  $\text{NH}_3$  - free distilled water. The steam was passed through the apparatus for 30 minutes and the blank was determined by collecting 50 ml of the distillate into a conical flask containing 5 ml of 2% boric acid, and titrated with 0.01 M HCl after mixed indicator (bromocresol green and methyl red) was added.

#### **(iii) *Measurement of $\text{NH}_4$ - N in compost and soil extracts*** **(Okalebo et al., 2002)**

Five millilitres (5 ml) of the 2% boric acid indicator solution was poured into a 50 ml conical flask and placed under the condenser of the steam distillation so that the end or tip of the condenser was about 40 cm above the surface of the boric acid indicator solution. An aliquot of 10 ml of the compost extract was pipetted into the distillation flask and about 0.2 g of MgO was added directly to reach the bulb of the distillation flask. The flask was then attached to the distillation apparatus and the stopcock on the steam- by pass tube closed. The tip of the condenser was rinsed with distilled water and the ammonium nitrogen in the various extracts of the compost was collected in the same way as described for steam. Ammonium -N content in the distillate was determined by titrating with 0.01 M HCl.

The colour changed at the end point from green to a permanent faint pink.

#### **(iv) *Measurement of $\text{NO}_3$ - N in soil and compost extracts*** (Okalebo et al., 2002).

After ammonium nitrogen was distilled from the sample extracts in the above, the stopper at the side arm of the distilling flask was removed and 0.2 g of Devarda's alloy was added. The stopper was then replaced immediately into the neck of the side

ammonium and nitrate nitrogen was distilled into fresh boric acid indicator. The  $\text{NO}_3$  is converted to  $\text{NH}_4$  and trapped in the conical flask.

This ammonium was then estimated by titrating with 0.01M HCl as described above.

### *Calculations*

Ammonium nitrogen ( $\text{NH}_4 - \text{N}$ ) and nitrate – nitrogen ( $\text{NO}_3 - \text{N}$ ) were each calculated as follows:

$$\% \text{ NH}_4 - \text{N} = 0.4 (a - b) \times \frac{v}{al} \times \frac{100}{w}$$

$$\% \text{ NO}_3 - \text{N} = 0.4 (a - b) \times \frac{v}{al} \times \frac{100}{w}$$

where,

a = Titre volume of 0.01MHCl for the sample (ml)

b = Titre volume for the blank (ml)

v = Volume of the extracting solution used – 40ml

al = Aliquot of solution taken

w= Weight of compost sample (mg)

(v) ***Measurement of total phosphorus (Perchloric acid digestion (wet oxidation) of plant materials for P, Ca, and Mg)***

### *Procedure*

Plant materials were oven-dried at 80 °C and ground, and 0.2g of the sample was weighed into a 125ml Erlenmeyer flask which was previously washed with acid and distilled water. Four mills (4ml) of perchloric acid, 25ml conc.  $\text{HNO}_3$  and 2ml conc.  $\text{H}_2\text{SO}_4$  were added to the sample under a fume hood. The contents were mixed and heated gently at low to medium heat on a hot plate under a perchloric acid fume

hood. The heating was continued until dense white fumes appeared. This again was finally heated strongly (medium to high heat) for half a minute and allowed to cool. Fifty millilitres (50ml) of distilled water was added and boiled for half a minute on the same plate at medium heat. After the solution had cooled it was filtered completely with Whatman No.42 filter paper, into a 100ml Pyrex volumetric flask and made up to the mark with distilled water. Phosphorus was determined colorimetrically using a spectrophotometer (Philip PU8620 UV/VIS/NIR model) at a wavelength of 712 nm. Calcium and magnesium were determined with a Perkin Elmer Atomic Absorption Spectrophotometer, Analyst 400.

#### *Calculation*

$$\text{P in sample (\%)} = \frac{\text{meter reading} \times \text{volume of digest} \times 100}{\text{weight of sample} \times \text{volume of aliquot} \times 10^6}$$

$$\text{Ca in sample (\%)} = \frac{\text{Absorbance} \times \text{volume of digestion} \times 100}{\text{weight of sample} \times 10^6}$$

$$\text{Mg in sample (\%)} = \frac{\text{Absorbance} \times \text{volume of digestion} \times 100}{\text{weight of sample} \times 10^6}$$

#### **(vi) Determination of available phosphorus (Bray No.1 Method)**

##### *Procedure*

##### *Extraction*

One gram (1g) of air-dried compost that had passed through a 2mm sieve was weighed into a 100ml conical flask and 7ml of extracting solution added to it. The content of the flask was on a shaking machine for 5 minutes and filtered through

Whatman No.42 filter paper. A blank was prepared by adding all the reagents similarly, except the soil. Phosphorous was determined calorimetrically as described in the above under total P.

#### *Calculation*

$$\text{Avai. P in sample (\%)} = \frac{\text{flame reading} \times \text{volume of extraction} \times 100}{\text{weight of sample} \times \text{volume of aliquot} \times 10^6}$$

#### **(vii) Measurement of total potassium**

##### *Procedure*

Compost samples were air-dried and sieved through 2.0mm mesh and 0.2g of the sample was weighed into a conical flask and digested with 5 ml Ternary mixture (20ml of 60% conc. perchloric acid, 500ml conc. nitric acid mixture and 50ml H<sub>2</sub>SO<sub>4</sub>). The compost- acid mixture was digested in a fume chamber till digest turned white. The digest was allowed to cool and filtered into 100ml volumetric flask which was top up to the mark. Because of the high concentration of K 10 ml aliquot of the digest was taken into 100ml volumetric flask and top up with distilled water to the mark. The concentration was read by aspirating into Jenway flame photometer (PFP7) that was calibrated at 25ppm.

##### *Calculation*

$$\text{Calculation: \% Total K} = \frac{\text{flame reading} \times \text{digest volume} \times 100\%}{\text{weight of sample} \times 10}$$

**(viii) Available potassium (Ammonium acetate extraction method) in soil**

*Procedure*

Five (5) grams of soil sample that was air-dry and sieved through 2.0mm was weighed into extraction bottle, and 100ml of 1 M ammonium acetate solution was added. The bottle with its contents was shaken on a mechanical shaker for one hour. After that the extraction mixture was centrifuged about 20 minutes. The supernatant solution was then filtered through No. 542 Whatman filter paper. The concentration of potassium in the filtrate was similarly determined with flame photometer as in section in the above.

*Calculation*

$$\text{Avail K (mgKg}^{-1}\text{)} = \frac{(a-b) \times v \times f \times 1000}{1000 \times w}$$

where

a = titre value (volume of the titre HCl for the sample)

b = blank value

v = final volume of the digest

w = weight of the sample taken in grams

f = dilution factor

### **3.2.6 Experimental Design for Growth Performance**

The design of the pre-nursery and nursery was Randomised Complete Block Design (RCBD) with three replicates. The experimental unit for the nursery was 8.4m x 4.8m consisting of eleven treatments for OPRI oil germinated nuts and seven treatments for La Mé oil palm germinated nuts from GOPDC. Each treatment also consisted of eight germinated oil palm seedlings. The total plot size was 30m x 11m.

Oil palm seedlings in the bigger polythene bags were arranged in a triangular pattern at a spacing of 90cm x 90cm x 90cm. Four central plants from each treatment were used as experimental plants.

### **3.2.7 Treatments**

The treatments were 15:15:15NPK, 4:4:8 Flanamite (imported organic fertilizer) and nine different composts prepared from various combinations of palm residues, cocoa pod husks, poultry droppings and or rock phosphate (Table 3.5).

Table 3.5: Chemical Composition of the Different Treatments Used to Establish the Nursery

<b>Treat</b>	<b>pH</b>	<b>C%</b>	<b>N %</b>	<b>NH<sub>3</sub> %</b>	<b>NO<sub>3</sub>%</b>	<b>P%</b>	<b>Available P%</b>	<b>K%</b>	<b>Available K%</b>	<b>Mg%</b>	<b>Ca%</b>
CA+SS	6.00	5.65	0.20	0.02	0.14	0.01	0.004	0.12	0.002	0.0024	0.002
CC+SS	5.06	12.95	0.23	0.02	0.08	0.06	0.001	0.10	0.005	0.0036	0.001
CD+SS	4.77	10.50	0.53	0.02	0.14	0.03	0.020	0.09	0.005	0.0027	0.002
CE+SS	4.66	15.59	0.59	0.02	0.23	0.02	0.022	0.11	0.001	0.0032	0.003
CG+SS	5.96	10.14	0.51	0.02	0.20	0.06	0.046	0.14	0.002	0.0044	0.004
CH +SS	6.15	13.54	0.59	0.04	0.17	0.07	0.027	0.12	0.002	0.0041	0.003
CI+SS	4.86	18.36	0.64	0.05	0.19	0.11	0.044	0.09	0.001	0.0037	0.002
CL+SS	4.86	10.50	0.60	0.04	0.18	0.03	0.022	0.09	0.001	0.0036	0.003
CM +SS	6.65	16.03	0.20	0.02	0.11	0.03	0.002	0.12	0.001	0.0026	0.002
Subsoil(SS)	4.20	0.96	0.15	0.03	0.02	0.42	*	*	*	*	*
Flanamite(F)	6.60	32.24	6.10	1.05	0.12	1.31	*	*	*	*	*

\* Not applicable

CA + SS = EFB + POME + subsoil

CC + SS = EFB + POME +MF + subsoil

CD + SS = EFB + PKC + WATER + subsoil

CE + SS = EFB + PKC + CH + POME + subsoil

CG + SS = EFB + PKC + CH + PD +WATER + subsoil

CH + SS = EFB + PKC + CH + PD +POME + subsoil

CI + SS = EFB + PKC + RP +POME + subsoil

CL + SS = EFB + PKC + POME + subsoil

CM +SS = EFB +WATER+ subsoil

### 3.2.8 Field Operation and Data Collection

#### *Pre-nursery and nursery establishment*

Oil palm pre-nursery was established on 1<sup>st</sup> July, 2003. Eight hundred Polythene bags of size (11.5cm x 16cm) were initially filled with a mixture of compost and sub soil (Kokofu, Kakum series) at the ratio of 1:2 (v/v) for seedlings receiving compost treatments. For the control, sub soil alone was used. Six hundred germinated oil palm nuts obtained from Oil Palm Research Institute (OPRI) and two hundred from Ghana Oil Palm Development Company (GOPDC) were planted on the 28<sup>th</sup> June 2003. The seedlings stayed at the pre-nursery for four months.

The seedlings were watered every other day. A month after establishment 5g of 15-15-15 NPK was dissolved in five litres of water and applied every fortnightly to the seedlings serving as control for three months (GOPDC, 2003). An equivalent fifteen grams (in terms of nitrogen) of 4-4-8 percent Flanamite was also dissolved in five litres of water and applied as in the case of NPK fertilizer to seedlings receiving Flanamite treatments. Seedlings receiving compost treatments did not receive any further compost addition throughout the pre-nursery period.

At the end of the fourth month seedlings were transferred with the bulk of the earth from the smaller polythene bags into the bigger polythene bags of size (30cm x 30cm) where it grew till the end of the nursery period. Seedlings receiving NPK were transferred into larger polythene bags containing 1.5 kg subsoil. Thereafter, 5g, 10g, 15g, 20g, 25g... of 15-15-15 NPK were applied for each month respectively (GOPDC, 2003). Seedlings receiving compost treatments were also transferred into polythene bags containing 1.5kg compost and subsoil mixture at the ratio of 1:2 (v/v). Seedlings receiving Flanamite treatments were also transferred into polythene

bags containing 1.5 kg subsoil. As in the case of inorganic fertilizer, an equivalent amount of composts or Flanamite (in terms of nitrogen content i.e. 15g, 30g, 45g & 60g) were respectively applied to seedlings receiving compost or Flanamite treatments for additional four months. Some of the seedlings were also transferred into 1.5 kg compost or Flanamite and subsoil mixture at a ratio of 1:2. All the seedlings were mulched with mesocarp fibres on the field. The mean number of leaves, leaf width, leaf length, seedling height and bole diameter were measured every month with meter rule and Vernier callipers from the fourth month to eight month and the results are presented in Tables 4.11 and 4.12. Root volume was measured by the displacement method. The roots were separated from the other parts of the oil palm seedlings, washed and gently placed in a 100ml graduated cylinder filled with water to the brim. The displaced water was collected and measured. This represents the root volume.



**Plate 3.7. Prenursery Showing Lamé Seedlings**



**Plate 3.8: Nursery Showing Transplanted Oil Palm Seedlings at Four Months Old**

### **3.2.9 Plant Analysis**

Three oil palm seedlings were randomly harvested from each treatment at the end of the eight months. The plants were cut at the base of the bole and separated into roots, bole + petiole and leaves. Thereafter the different parts of the samples

were oven - dried at 80°C for three days and ground with a mill after taking the dry weights. Plant tissues were analysed for total nitrogen (N) content using modified Kjeldahl method after digestion with H<sub>2</sub>SO<sub>4</sub> and hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>)(Black, 1965). Phosphorus (P) content was analysed according to Bray and Kurtz (1945) after perchloric acid digestion method described by Chapman (1978). Potassium after perchloric acid digestion was determined by flame photometry. Similarly calcium and magnesium contents were determined by Atomic Absorption Spectrophotometer (AAS).

#### ***Determination of nutrient uptake***

$$\begin{aligned}\text{Nutrient uptake} &= \text{dry matter yield} \times \% \text{ nutrient concentration} \\ &= \text{DMY} \times \frac{\text{NUT.CONC.}}{100}\end{aligned}$$

#### **3.2.9 Statistical Analysis**

All data were subjected to statistical analysis. Where the analysis of variance indicated significant differences among the treatment means, LSD test was used to separate the means. All comparisons were done at 1% and 5% level of significance. Also, multiple regressions were used to show correlation between two or more variables

## CHAPTER 4: RESULTS

### 4.1 CHARACTERISATION OF RESIDUES GENERATED BY OIL PALM INDUSTRY, IMPACT ON THE ENVIRONMENT AND TREATMENT ALTERNATIVES

#### 4.1.1 Oil Palm Mills in the Kwaebirem District

Twenty-two prominent oil processing mills were identified in the district. These included 20 small scale mills (Plate 4.1), and a highly automated medium and large scale mills (Plate 4.2). The number of years that the mills have been in operation is shown in Table 4.1.

Table 4.1: Years of Operation by Oil Processing Mills in the Kwaebirem District

Year	Frequency	
	Number	%
Less than 2 years	4	18
Between 2-5 years	4	18
Between 6-9 years	7	32
Between 10 -20 years	6	27
Above 20 years	1	5
<b>Total</b>	<b>22</b>	<b>100</b>



Plate 4.1: Small Scale Oil Palm Processing Company at Kade, Awoyo No 1



Plate 4.2: Palm Oil Mill belonging to the Ghana Oil Palm Development Company (GOPDC)

#### 4.1.2 Milling Processes

The main raw material supplied to the mills is fresh fruit bunches (FFB). About 143,588 metric tonnes of FFB was processed in 2003 by the twenty-two mills in the Kwaebibirem District. Crude palm oil (CPO) produced was about 32,000 metric tonnes which was about 4.5% of the total national production in 2003. The palm oil Mill at GOPDC has a capacity of 48 tons/hr with an extraction rate of about 20% of oil and a palm kernel crushing plant of 45 tons/day. In 2003, GOPDC produced 20,000 metric tonnes of CPO and 1,500 tons of palm kernel oil. The production capacity of these medium and small scale mills ranged between 1.5-4.0 metric tonnes FFB per hour with an extraction rate between 12-15% of the oil. They together produced about 10,000 metric tonnes of palm oil in 2003. The technology used by the small scale mills is seeming on a scale down model of the large scale Mills. The small scale processing Mills use semi-mechanised processing method whilst the medium and large scale Mills employ the standard oil extracting process (normally called the wet process) where water is added into a digester. The process of oil extraction for both small scales and large scale Mills is summarised in Figures 4.1 and 4.2. The components of fresh fruit bunches are also shown in Figure 4.3.

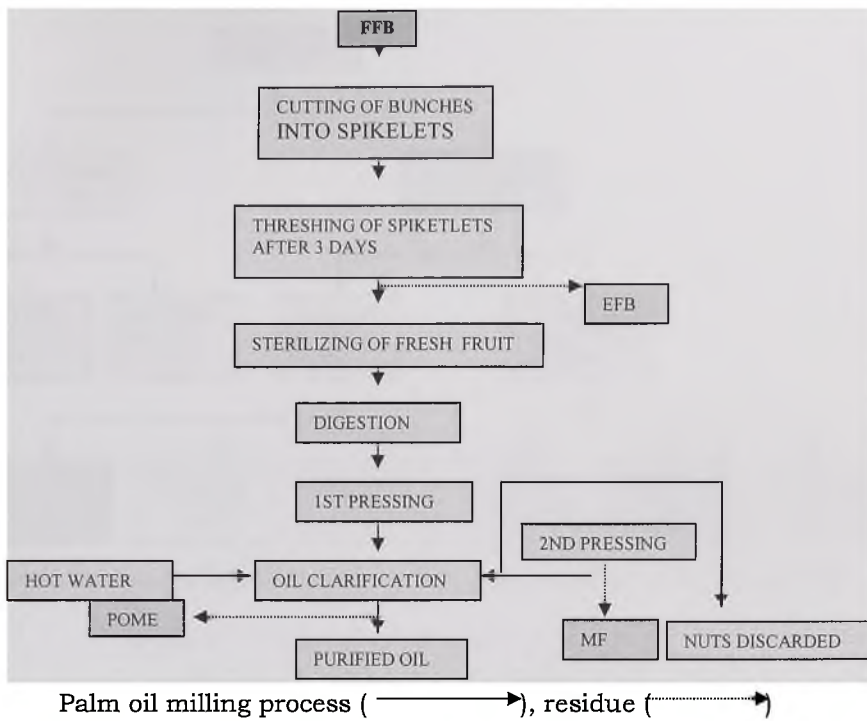


Figure 4.1: Flow Chart Showing Palm Oil Milling Process on the Small Scale

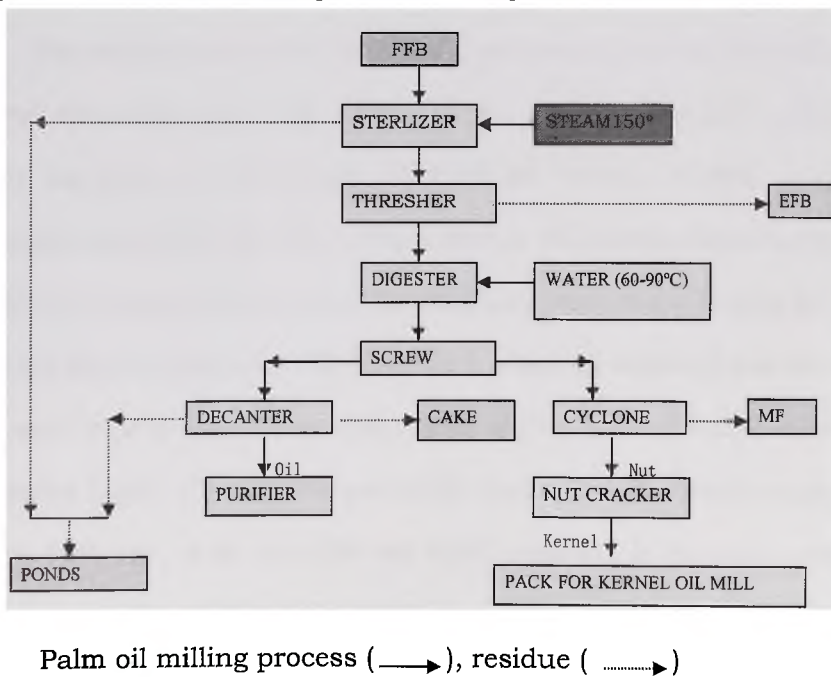
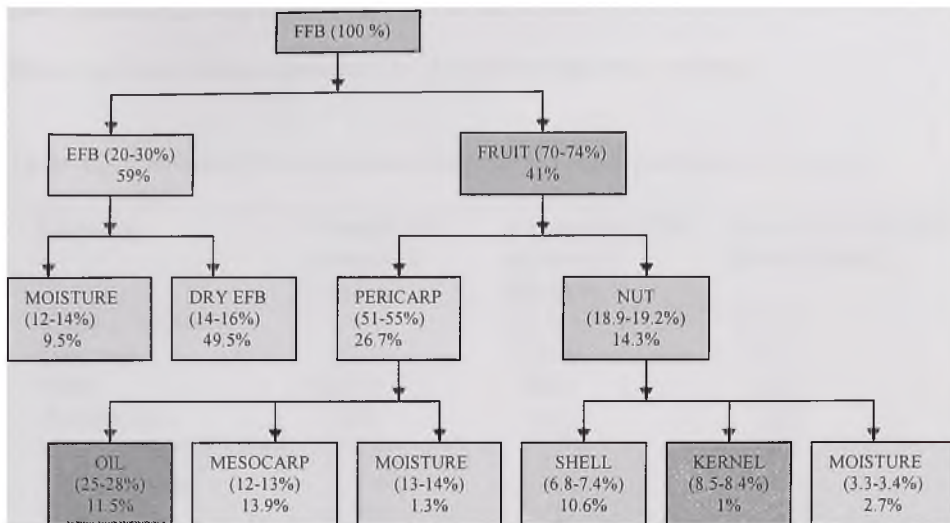


Figure 4.2: Flow Chart Showing Large Scale Palm Oil Milling Processing Units e.g. GOPDC



Numbers in brackets are high quality FFB and those without bracket are low quality FFB

Figure 4.3: Composition of Fresh Fruit Bunch (FFB)  
Source: Prasertsan and Prasertsan (1996)

#### 4.1.3 Types and Amount of Residues Generated by Palm Oil Processing Mills

The residues generated by the palm oil processing mills were identified as palm kernel shell (PKS) empty fruit bunches (EFB), mesocarp fibre (MF), sludge cake (SC) and palm oil mill effluent (POME)(Plate 4.3-4.6). GOPDC in addition generates palm kernel cake (PKC). This is because the company extracts kernel oil in addition to the palm oil processing. The small-scale processing mills heap the kernels and sell them to other Kernel Oil Mills which extract the kernel oil from the seed of the nuts. In 2003 about 33,025 metric tonnes of EFB and 73,229 m<sup>3</sup> of POME were generated (Table 4.2). The EFB and POME produced in the district accounted for about 5.2% each of the total EFB and POME generated in the entire country for 2003. The medium and small-scale mills generated about 35% and 38% of EFB and POME, respectively, whilst GOPDC accounted for the generation of the remaining 65%-62%. Table 4.2 shows the amount of residues generated by some selected oil

palm processing mills in the year 2003 in the Kwaebibirem District, whilst Table 4.3 shows the total residues generated by the mills in the entire country.

Table 4.2: Amount of Palm Residues Generated in the Kwaebibirem District in 2003

Location	Fresh fruit processed (tonnes)	Amount of EFB produced (tonnes)	Amount of POME produced(m <sup>3</sup> )
Kwae (GOPDC)	91,604	21,069	46718
Damang	7,200	1,656	3672
Subi	16,800	3864	8568
Adankrono	1,920	442	979
Okumaning(UGARS)	960	221	490
Nkwantanang	7,680	1,766	3917
Kusi	4,944	1,137	2521
Takorowase	912	210	465
Kade	2,640	607	1346
Asuom	8,928	2,053	4553
Total	143,588	33,025	73,229

Table 4.3: Area under Oil Palm Cultivation, Amount of Fresh Fruit Bunch and Palm Residues Generated in the Country

Year	Production* (tons)	Area under cultivation (ha)	Quantity of EFB generated (tons)	Quantity of POME generated (m <sup>3</sup> )
1989/90	470,430	42,766	108,199	239,919
1990/91	508,780	46,253	117,019	259,478
1991/92	544,970	49,543	125,343	277,935
1992/93	572,990	52,090	131,788	292,225
1993/94	418,910	38,035	96,349	213,644
1994/95	478,980	43,544	110,165	244,279
1995/96	481,910	43,810	110,839	245,774
1996/97	532,350	48,395	122,441	271,499
2003	3135,000	285,000	721050	1598850

\* Calculation of oil palm production was based on average yield of eleven (11) tonnes per hectare as estimated over eight year period, 1989-1997 (Toledano et al., 2004). Also, total residues generated was calculated based on the total amount of fresh fruit bunch processed. For every metric tonnes of fresh fruit bunch (FFB) processed 23% of it is made up of EFB and 51% of the FFB is made up of POME (Ma et al, 1993).



Plate 4.3: Heaps of Empty Fruit Bunch (EFB)



Plate 4.4: Heaps of Palm Kernel Cake (PKC)



Plate 4.5: Heaps of Mesocarp Fibre (MF)



Plate 4.6 : Pond Containing Palm Oil Mill Effluent (POME) at GOPDC

#### 4.1.4 Chemical Composition of Oil Palm Residues

Table 4.4 shows the chemical characteristics of EFB, MF, PKC and POME. The pH values for MF and PKC ranged between 4.5 and 6.0 whilst that of EFB was 9.0. Similarly, the pH of the fresh POME was between 4.6 and 4.8 (Table 4.5).

Table 4.4: Chemical Characteristics of Palm Residues

Wastes	pH	Moisture content (%)	Organic matter (%)	Total nitrogen (%)	C/N	Phosphorus (%)	Potassium (%)
EFB	9.0	56	72.03	1.40	29.76	0.49	2.10
MF	6.0	33	70.75	1.30	31.48	0.20	0.44
PKC	4.5	4	68.01	1.65	23.84	0.70	0.50
POME	4.6	16	54.20	1.80	17.42	0.30	0.06

Nitrogen content ranged between 1.30-1.80 %. Among the residues PKC showed highest phosphorus content (0.7%) while MF recorded the least (0.20%). Potassium content was highest in EFB (2.10%) and lowest in POME.

#### 4.1.5 Comparison of the Chemical Composition of POME Generated by the Large Scale and Small Scale Oil Processing mills

There were differences in the chemical composition of the treated POME discharged to the environment by GOPDC at Kwae and the untreated POME discharged by the small scale mills (Table 4.5). The pH for the treated POME was 8.0 (i.e. basic) whilst that of the untreated was less than 5 (i.e. acidic). Similarly, the electrical conductivity of the treated POME was 10.4  $\mu\text{S}/\text{cm}$  whilst that of the untreated ranged between 34.1  $\mu\text{S}/\text{cm}$  at Adankrono to 31,300  $\mu\text{S}/\text{cm}$  at Subi.

Table 4.5: Variations in Chemical Characteristics of Palm Oil Mill Effluent (POME)

Sample location	pH	EC $\mu\text{S}/\text{cm}$	SS $\text{mg}/\text{l}$	TDS $\text{mg}/\text{l}$	TS $\text{mg}/\text{l}$	COD $\text{mg}/\text{l}$	BOD $\text{mg}/\text{l}$	Oil $\text{mg}/\text{l}$
Okumaning	4.6	3,600	137,333	43,167	180,500	66,880	30,400	161,112
Kusi	4.7	7,910	158,600	51,400	180,000	112,640	35,200	147600
Damang	4.7	5,650	105,500	91,850	197,370	98560	39,424	102,558
Subi	4.8	31,300	142,900	46,500	189,400	41000	18,251	15910
Adonkrono	4.7	34.1	460,800	181,200	642,000	133,760	44,586	560,250
Kwae(GOPDC)	8.1	10.4	450		1000	928	495	134.5
<b>Ghana EPA Standard for waste water</b>	(6-9)	(1500)	(55)	(1000)	-	(250)	(50)	(5)
<b>Malaysian Standard for palm oil mill effluent (Maheswaran 2003)</b>	(5-9)	(1500)	(400)	-	(1500)	(1000)	(500)	(50)

Total dissolved solids among the small scale mills varied from a minimum of 43,167mg/l at Okumaning to a maximum of 181,200 mg/l at Adankrono. The COD of the treated POME was 928 mg/l while that of the untreated ranged between 41,000 and 133,760 mg/l. Similarly, the BOD of the treated POME was 495 mg/l while that of the untreated ranged between 18,000 and 44,586 mg/l. There was also a wide variation in the oil content of the treated and the untreated POME (Table4.5).

#### **4.1.6 Methods Used by the Small and Large Scale Oil Processing Mills to Manage Oil Palm Residues in the Kwaebibirem District**

The small and medium scale oil processing mills use the EFB and MF as fuel in steaming FFB. The resultant ash is either used for soap making or as fertilizer. The EFB is also used as mulch on farms and plantations. However, the POME is not treated at all before discharging into the environment (Plate 4.7).

GOPDC similarly, heaps and uses the EFB and MF as mulch on oil palm plantation and nurseries. The company uses the palm kernel shell to generate energy to run the mill whilst the PKC is used to feed cattle (Plate 4.8). The POME is also treated through the pond system (i.e. anaerobic digestion) before discharging it into the environment.



Plate 4.7: Untreated POME Discharged near Water Course



Plate 4.8: Cattle Feeding on PKC at GOPDC

Figure 4.4 shows a pie chart of the different methods used by the mills to manage the solid residues. Gradual use of EFB and MF as fuel cover about 68 %, and the use on farms as mulch covers about 14 %. On the other hand the use of the EFB and MF as fuel and ash in making soap covers 9% whilst 9% use the ash only as fertilizer.

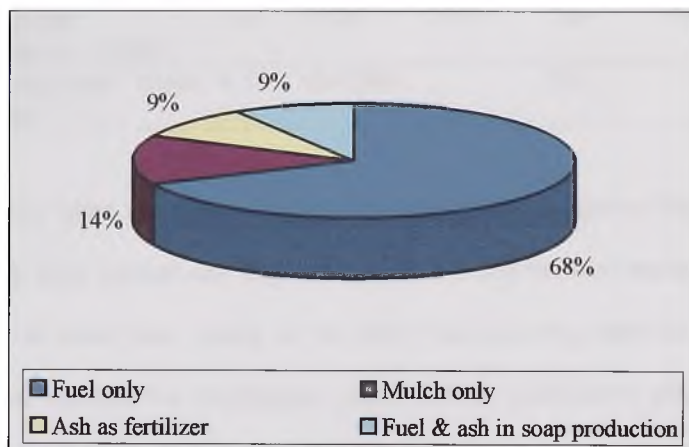


Figure 4.4: Percentage Occurrence of Methods Being Used to Manage EFB and MF

#### 4.1.7 Impact of Oil Palm Residues on Water Bodies near Small Scale Oil Processing Mills

The pH values of the three different water bodies ranged between a minimum of 5.9 to a maximum of 7.2. Mean dissolve oxygen (DO) concentrations in the water bodies were below 3.0 mg/l at six different sites with the exception of Kade Birim River. The BOD values of Kadepon and Kadewa streams where most of the small scale mills are sited were between 4.80 to 14.40 mg/l. This study infers the results by comparing it to the physico-chemical properties of the residues especially the untreated POME (Table 4.5).

Table 4.6: Physico-Chemical Characteristics of Three Different Water Bodies in the Kwaebibirem District

Sample sites	pH	EC $\mu\text{S/cm}$	TSS $\text{mg/l}$	BOD $\text{mg/l}$	COD $\text{mg/l}$	DO $\text{mg/l}$
Kadepon upstream	5.9	114.00	42.0	7.40	96.70	1.95
Kadepon midstream	7.0	147.00	48.0	4.80	166.70	1.85
Kadepon downstream	6.9	142.00	42.0	7.20	65.90	2.1
Kadewa upstream	6.6	127.20	38.0	10.80	51.20	0.93
Kadewa midstream	6.7	116.30	36.0	13.20	99.87	1.23
Kadewa downstream	6.8	120.00	52.0	14.40	95.45	1.50
<u>Kade Birim River</u>	7.2	98.00	52.0	5.6	36.67	5.80
<i>Source: Hodgson, (2002)</i>						
Natural background range for fresh water	6.5-8.5	10-1000		2.0	8.0 at 25°C	

Secondly, there were personal interactions with the managers of the mills as to whether they have noticed any impact of the POME on the environment. GOPDC complained of odour and dying of oil palm trees growing near the ponds and channels that conduct the discharged treated POME (Gert,2003) (Plate 4.9).The small scale mills complained about bad odour. Furthermore, personal observation from one of the mills where the untreated POME was being deposited showed some dead snails, millipedes and other organisms (Plate 4.10).



Plate 4.9: Effect of Treated POME on Oil Palm Growth near Ponds



Plate 4.10: Effect of Untreated POME on Soil Organisms

## 4.2 BIOCHEMICAL CHANGES DURING COMPOSTING OF AGRICULTURAL AND AGRO-INDUSTRIAL RESIDUES AND DETERMINATION OF COMPOST MATURITY

### 4.2.1 Chemical Characteristics of Composting Materials

The chemical composition of the various materials used for the composting process is shown in Table 4.4 and 4.7. The pH for cocoa pod husks (CH) and poultry waste (PW) are basic (8.5-9.2). POME had the smallest C/N ratio (17.42) whilst PW had the highest (43.92). Total phosphorus was highest in the poultry waste (2.21%) but mesocarp fibre and cocoa pod husks showed lower values (0.20-0.07%). Cocoa pod husks recorded highest value for potassium followed by PW and EFB.

Table 4.7: Chemical Composition of Cocoa Pod Husks and Poultry Waste Used as Amendments in the Composting Process

Wastes	pH	Moisture content (%)	Total carbon (%)	Organic matter (%)	Total nitrogen (%)	C/N	Phosphorus (%)	Potassium (%)
CH	9.2	45	46.70	80.74	1.47	31.77	0.17	3.35
PW	8.5	*	58.41	90.40	1.33	43.92	2.21	2.55

\*Not determined

### 4.2.2 Composting Process and Evaluation of Compost Maturity

Temperature, carbon dioxide evolution (used to represent microbial activity), C/N ratio, pH, ammonium- nitrogen, nitrate- nitrogen concentration, and germination index were the parameters measured.

#### *Temperature of compost*

Heat was generated by all the treatments; however, the values differed depending on the composting mixtures. The changes in the temperature for the

different treatments are presented in Figure 4.5. The highest temperature was recorded during the 8<sup>th</sup> week (62 °C) for treatment CE (EFB + PKC + CH + POME). Thereafter the temperature declined gradually and by the end of the 16<sup>th</sup> week the temperature had reduced to 26 °C. Treatment CI, (EFB + PKC + RP +POME ) was the next which reached 60 °C at the 9<sup>th</sup> week and remained constant until the 12<sup>th</sup> week when the temperature started declining until it reached 30 °C at the end of the 16<sup>th</sup> week. On the other hand the temperature of treatment CA, (EFB + POME) never went beyond 40°C. A temperature of 39 °C was obtained at the 1<sup>st</sup> week and 28°C at the 16<sup>th</sup> week. Treatment CC (EFB + POME +MF) also recorded high temperature reading at the 1<sup>st</sup> week (39°C) and thereafter started declining reaching 27 °C at the end of the 16<sup>th</sup> week, behaving similar to treatment CA.

#### *Carbon dioxide (CO<sub>2</sub>) evolution (microbial activity)*

Figure 4.6 shows the patterns of CO<sub>2</sub> evolution from the different compost treatments. In general the CO<sub>2</sub> evolution for all the four compost treatments decreased with time over the 18 weeks period, until a final stable value was attained. The value ranged between 1.0-6.8 mg CO<sub>2</sub> g<sup>-1</sup>d<sup>-1</sup>. From 98 days onwards all the treatments appeared to have stabilized with values near 2.0 mg CO<sub>2</sub> g<sup>-1</sup>d<sup>-1</sup> except treatment CA which was 6.8 mg CO<sub>2</sub> g<sup>-1</sup>d<sup>-1</sup> at 138 days.. In treatment CA, CO<sub>2</sub> evolution decreased from 17.12 mg g<sup>-1</sup>d<sup>-1</sup> at the 7<sup>th</sup> day to 11.60 mg g<sup>-1</sup>d<sup>-1</sup> at the 50<sup>th</sup> day, but this increased again to 16.10 mg g<sup>-1</sup>d<sup>-1</sup> at the 78<sup>th</sup> day and thereafter started decreasing until the end of the composting period. Treatment CI also had its CO<sub>2</sub> evolution increasing from 17.30 mg g<sup>-1</sup>d<sup>-1</sup> at the 7<sup>th</sup> day to 23.50 mg g<sup>-1</sup>d<sup>-1</sup> at the 50<sup>th</sup> day before it started decreasing. The CO<sub>2</sub> evolution for the two treatments, CC and CE on the other hand decreased gradually till the end of the composting period.

### *C/N*

The C: N ratio of all the organic residue mixtures decreased during the composting process (Figure 4.7) especially in the treatment with high initial C: N ratio (i.e. treatment CC). Whilst treatments CC and CA showed continuous decrease in C: N ratio that of treatments CE and CI showed an increase after 50 days. Meanwhile, the initial values, which ranged from 23.71 to 44.31, decreased to 7.10 to 12.8 after maturity.

### *pH*

At the onset of the composting process the pH of the compost treatments ranged between 5.6 and 6.1, however by the end of the process this had increased to 6.4 and 7.1 (Figure 4.8). The pH values of treatment CA rose from 6.10 to 7.70 and then began to fall around 50 days after. Treatment CE also had the pH dropping from 5.9 on day 7 to 5.10 at 50 days. The pH then started to rise gradually till it reached 7.20 on day 98, when it started to decrease again. Treatment CC had the pH raised from 6 on day 7 to a maximum of 8.7 on day 78 and then began to decrease until it got to 7.9 at 138 days. Similarly, treatment CI also followed the same trend, from 5.6 at day 7 to 7.5 at day 78 and 6.4 at 138 days. In general the pH of the matured composts was slightly higher than that of the initial composting mixtures.

### *Ammonium and nitrate nitrogen concentration ( $NH_4$ )*

The level of ammonium nitrogen ( $NH_4^+$  -N) at the beginning of the composting process was low (between 0.06 and 0.1%) but increased and attained highest value at 78 days (between 0.26 and 1.65%) after which it started to decrease (Figure 4.9). For treatment, CI, the ammonium –nitrogen value increased up to 1.65% at 78 days but decreased to 0.1% by 138 days. Treatment CE was the next

highest at 78 days. It had a value of 1.16% but declined to 0.1% at 138 days. Treatments CA and CC recorded values of 0.26% and 0.14%, respectively, at 78 days but both declined to 0.06% at 138 days.

Nitrate-nitrogen values on the other hand were low from the beginning (0.03%-0.06) and increased to 0.13%-0.35% by the end of the composting period (Figure 4.10).

#### *Germination index (GI %)*

The compost treatments showed germination index less than 100% between the 1<sup>st</sup> to 98 days after composting (Figure 4.11). After 98 days, treatments CC and CE recorded values more than 100%. Treatment CI recorded 97% at 98 days and even at 138 days after composting while treatment CA still recorded values less than 70%.

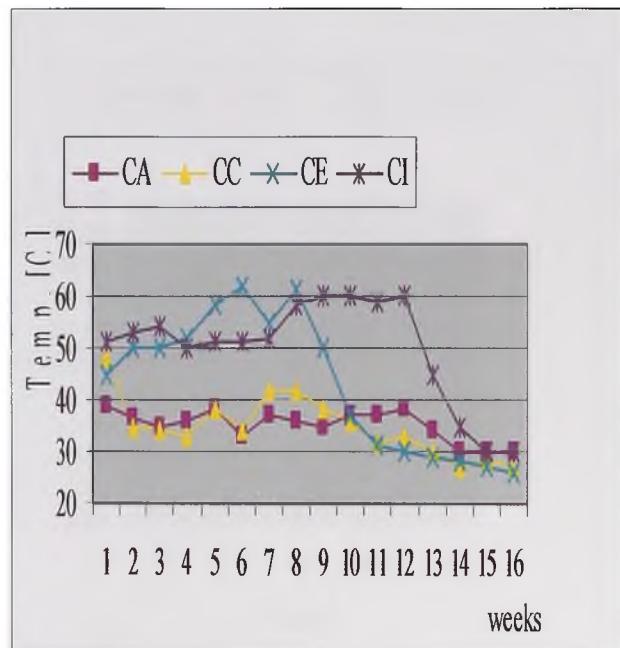


Figure 4.5: Temperature Changes during Composting of the Different Organic Residue Mixtures (°C)

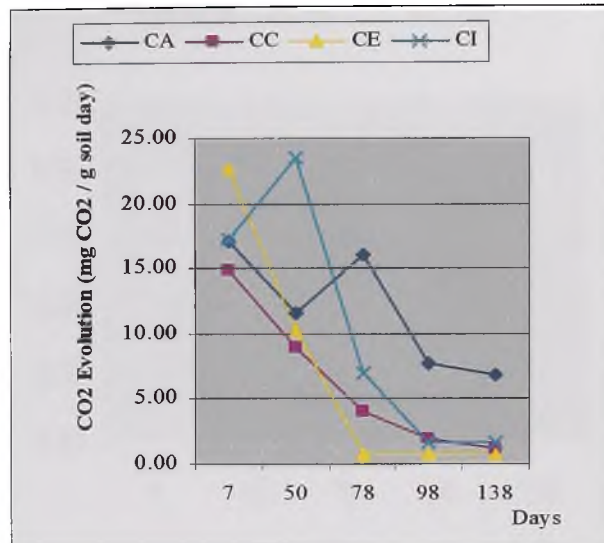


Figure 4.6: Changes in CO<sub>2</sub> Evolution during Composting of the Different Organic Residues

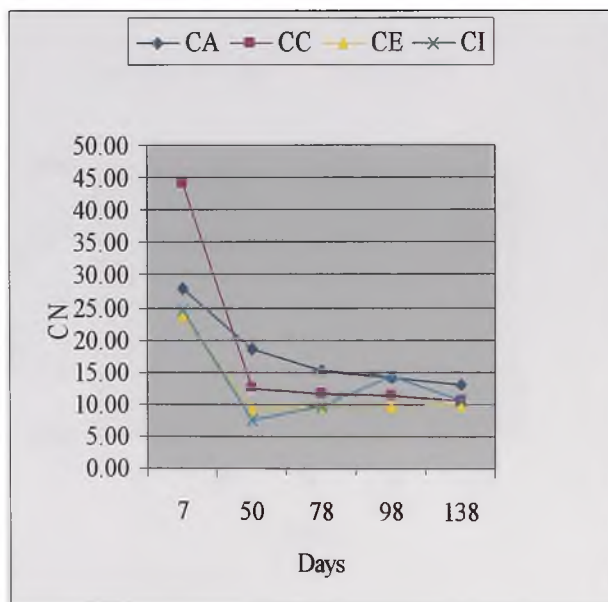


Figure 4.7: Changes in C: N Ratios During Composting Process

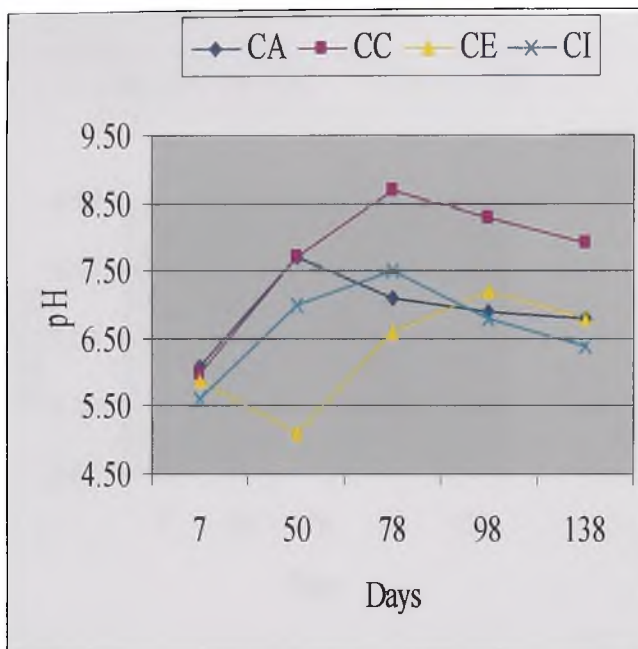


Figure 4.8: Changes in pH During Composting Process

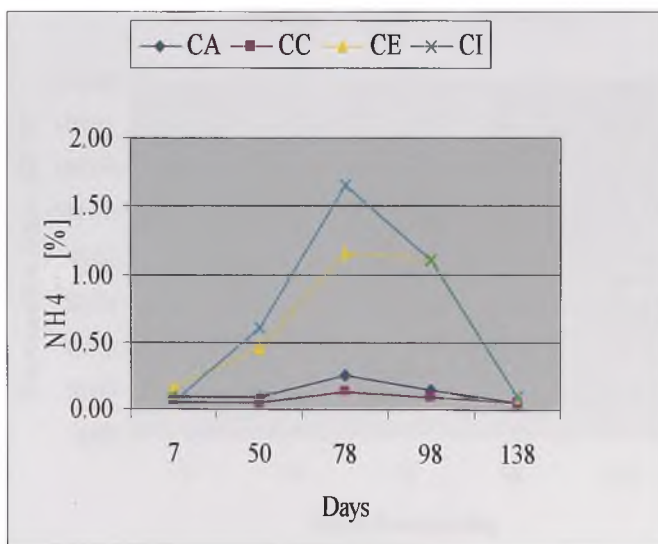


Figure 4.9: Ammonium -N Levels during Composting Process

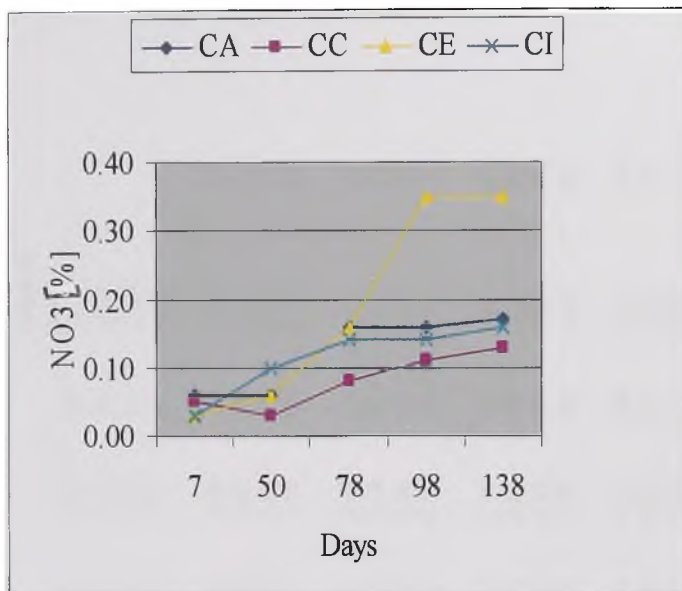


Figure 4.10: Nitrate-N Levels during Composting Process

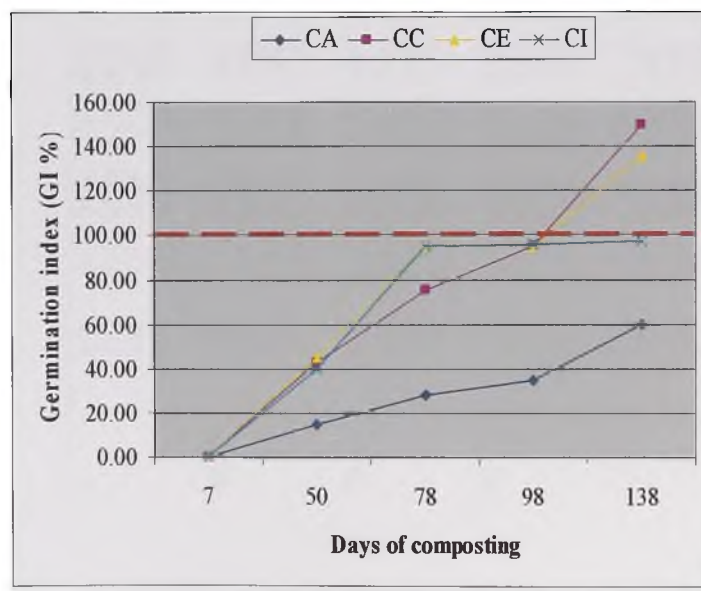


Figure 4.11: Effect of Days (time) of Composting on Germination Index



#### 4.3 EFFECTS OF DIFFERENT ORGANIC WASTE MIXTURES ON CHEMICAL CHARACTERISTICS OF MATURED COMPOST

This study examined the effect of different composting materials on compost quality. The parameters that were measured included pH, organic matter content and nutrient levels (Table 4.8b). Earlier study on composting materials revealed insignificant levels of heavy metal contamination (Ofosu-Budu, in press).

##### 4.3.1 pH

The pH values for matured compost ranged between 6.0 in treatment CL and CM to 7.9 in CC (Table 4.8b). There were significant differences among the pHs of the following treatments: CA and CC; CA and CM; CG and CH; CE and CL; CH and CK, and CB and CE. Significant differences were however not observed among treatments CB and CD; CD and CL. In general, treatments containing POME recorded highest pH, except CI, CK and CL.

##### 4.3.2 Organic matter

CJ was the lowest, and the only treatment with organic carbon less than 30%. Those that fell within 30 to 40% were CM, CK, CH CG and CC with treatment CI, CE, CA, CL, CB and CD registering greater than 40% organic carbon.

##### 4.3.3 Total Nitrogen

Percent nitrogen content of the different compost treatments ranged between 2.0% in treatment CM and 4.5% in CD. CM and CL were the only compost

treatments registering total nitrogen less than 3%. Treatments CJ, CA, CK, CC, CG, CI and CB registered total nitrogen between 3 to 4 % while treatments CE, CH, and CD registered total nitrogen greater than 4%. Whereas there were no significant difference among treatments CA and CC, CG and CH, CH and CK, CE and CI, CI and CK, significant differences were observed among treatments CA and CM, CE and CL.

Table 4.8b: Effect of Different Organic Mixtures on Chemical Characteristics of Compost at Maturity

Sample	pH	C (%)	N (%)	NH <sub>4</sub> -N (%)	NO <sub>3</sub> -N (%)	P (%)	K (%)	Ca (%)	Mg (%)
CA	7.1	41.58	3.24	0.06	0.17	0.46	2.13	0.04	0.11
CB	6.4	43.83	3.92	0.13	0.30	0.85	3.88	0.03	0.11
CC	7.9	40.38	3.73	0.06	0.13	0.30	2.50	0.03	0.09
CD	6.2	45.78	4.51	0.48	0.03	1.23	2.60	0.04	0.08
CE	6.8	40.85	4.11	0.10	0.35	1.29	3.97	0.02	0.07
CG	6.4	38.40	3.80	0.11	0.24	2.48	3.00	0.03	0.20
CH	6.9	34.31	4.12	0.06	0.28	1.10	2.88	0.03	0.11
CI	6.4	40.55	3.90	0.10	0.16	4.46	2.13	0.13	0.19
CJ	7.0	25.22	3.20	0.05	0.03	3.78	1.11	0.05	0.15
CK	6.1	35.56	3.51	0.05	0.06	3.93	1.36	0.09	0.20
CL	6.0	42.24	2.60	0.06	0.02	0.99	0.68	0.01	0.11
CM	6.0	35.56	2.00	0.38	0.02	0.70	1.77	0.03	0.05
LSD	0.216	1.791	0.697	0.044	0.025	0.177	0.565	0.012	0.018

CA = EFB + POME

CB = EFB + PKC + CH + WATER;

CC = EFB + POME + MF;

CD = EFB + PKC + WATER

CE = EFB + PKC + CH + POME;

CG = EFB + PKC + CH + PW + WATER;

CH = EFB + PKC + CH + PW + POME

CI = EFB + PKC + RP + POME;

CJ = EFB + RP + POME

CK = EFB + PKC + RP + CH + POME

CL = EFB + PKC + POME;

CM = EFB + W

#### 4.3.4 Ammonium and nitrate nitrogen concentration

CD and CM were the only compost treatments with ammonium –nitrogen between 0.48 and 0.38%. Treatments CA, CC, CH, CJ, CK and CL registered less than 0.06% ammonium – nitrogen. Similarly, treatments CD, CJ, CL, and CM registered nitrate – nitrogen less than 0.03%. However, nitrate-nitrogen values greater than 0.20% were registered by treatments CB, CE, CG and CH (Table 4.8b).

#### **4.3.5 Phosphorus (P)**

Treatment CI registered highest level of phosphorus (4.4%) followed by CK (3.93%) CJ (3.78%) and CG (2.48). Conversely, treatments CC, CA, CM and CL registered less than 1.0% phosphorus. Whereas treatment CI was significantly higher than CK and CJ no significant differences was registered between treatments CK and CJ (Table 4.8b).

#### **4.3.6 Potassium (K)**

Treatments CB, CE, CG, and CH registered potassium content between 3.97 to 2.88 % (Table, 4.8b). However, potassium levels below 2.0% were registered within treatments CJ, CK, CL and CM. No significant differences were registered among treatments CB and CE, CG and CH. Conversely, significant difference was registered between CH and CK.

#### **4.3.7 Calcium and Magnesium**

Treatment CI recorded the highest value for calcium (0.13%). CI was significantly different from all the other treatments. Treatment CK was the next highest with a value of 0.09%. Conversely, treatments CL, CE, CB, CG and CH recorded the lowest value of Ca (between 0.1%- 0.3%). The highest magnesium content was recorded in treatments CK, CI and CG. There were no significant differences among treatments CK, CG and CI. However, these treatments were significantly different from the rest of the treatments.

#### 4.4 EFFECT OF COMPOST ON GROWTH AND NUTRIENT UPTAKE OF TWO OIL PALM VARIETIES

##### 4.4.1 Effect of Compost Treatments on Mean Number of Leaves, Leaf Width and Length, Seedling Height and Bole Diameter of OPRI Oil Palm Seedlings

*Mean number of leaves:* - Oil palm seedlings grown on compost treatments CH+SS (T<sub>7</sub>), CD+SS (T<sub>3</sub>) and CG +SS (T<sub>6</sub>) recorded significantly higher mean number of leaves as compared to that of inorganic fertilizer, CO +SS (T<sub>11</sub>) or Flanamite<sup>†</sup>, F + SS (T<sub>5</sub>). Among the compost treatments, seedlings from T<sub>7</sub>, T<sub>3</sub> and T<sub>6</sub> were significantly higher from the other compost treatments (Table 4.9a). Similarly, seedlings from compost treatment CA +SS (T<sub>1</sub>) were also significantly higher than those from CM +SS (T<sub>10</sub>). However, the mean number of leaves of seedlings from NPK treatment (T<sub>11</sub>) was better than seedlings from T<sub>10</sub> and T<sub>1</sub>. The order of mean number of leaves among compost treatments was

$$T_7 > T_3 > T_6 > T_4 > T_9 > T_8 > T_2 > T_1 > T_{11}$$

*Mean leaf width:* Except for compost treatment T<sub>7</sub>, there were no significant differences in the mean leaf width between the seedlings receiving the compost treatments, NPK (T<sub>11</sub>) and the Flanamite (T<sub>5</sub>). Similarly, only seedlings from compost treatments T<sub>1</sub> and T<sub>2</sub> (CC +SS), T<sub>6</sub> and T<sub>7</sub> recorded significant differences in the mean leaf width.

*Mean leaf length:* - Significant differences were observed between mean leaf length of seedlings from compost treatments T<sub>7</sub>, T<sub>4</sub> (CE +SS), NPK, T<sub>11</sub> and Flanamite (T<sub>5</sub>). Among the compost treatments, seedlings from treatment T<sub>7</sub> and T<sub>4</sub> were also significantly different in mean leaf length.

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<sup>†</sup> Flanamite is imported organic fertilizer (4%N:4%P:8%K)

*Mean seedling height:* - Seedling height of treatment T<sub>7</sub> was significantly higher than the control or the Flanamite (T<sub>5</sub>) (Table 4.9b) (Plate 4.11). The seedling heights of the NPK (T<sub>11</sub>) and Flanamite (T<sub>5</sub>) treatments were higher than that of T<sub>10</sub>. The order of mean leaf height decreased as follows: T<sub>7</sub>> T<sub>4</sub>> T<sub>3</sub>>T<sub>9</sub>>T<sub>2</sub>>T<sub>6</sub>>T<sub>11</sub>>T<sub>1</sub>> T<sub>5</sub>>T<sub>8</sub>>T<sub>10</sub>.

*Mean bole diameter:* - Bole diameter of seedling of treatments T<sub>7</sub>, T<sub>4</sub> and T<sub>3</sub> was significantly higher than the NPK (T<sub>11</sub>) and the Flanamite (T<sub>5</sub>). There were no significant differences among the remaining compost treatments. The order of mean bole diameter decreased as follows: T<sub>7</sub>> T<sub>4</sub>> T<sub>3</sub>>T<sub>9</sub>>T<sub>8</sub>>T<sub>6</sub>>T<sub>2</sub>>T<sub>1</sub>> T<sub>11</sub>>T<sub>5</sub>>T<sub>10</sub>.

Table 4.9a: Effect of Compost Treatments on the Mean Number of Leaves, Leaf Width and Length of OPRI Oil Palm Seedlings at 7 Months

Parameters Treat / months	Mean number of leaves					Mean leaf width(cm)					Mean leaf length (cm)				
	4M	5M	6M	7M	Mean	4M	5M	6M	7M	Mean	4M	5M	6M	7M	Mean
CA + SS(T <sub>1</sub> )	4.67	4.93	6.17	7.00	<b>5.69</b>	5.92	6.00	9.50	9.80	<b>7.81</b>	21.18	23.07	26.43	33.57	<b>26.06</b>
CC + SS(T <sub>2</sub> )	4.80	5.53	6.87	7.77	<b>6.24</b>	5.83	6.33	10.87	12.87	<b>8.97</b>	22.30	24.90	27.40	33.83	<b>27.12</b>
CD + SS(T <sub>3</sub> )	5.31	5.73	7.37	7.90	<b>6.58</b>	6.75	7.00	11.50	13.43	<b>9.67</b>	21.88	24.30	28.23	36.70	<b>27.78</b>
CE + SS(T <sub>4</sub> )	4.82	5.93	7.10	8.07	<b>6.48</b>	6.58	7.80	10.30	13.20	<b>9.47</b>	23.08	25.83	28.50	37.03	<b>28.61</b>
F + SS (T <sub>5</sub> )	4.78	5.27	6.70	7.63	<b>6.10</b>	5.52	7.03	10.00	13.50	<b>9.01</b>	21.49	24.43	27.03	33.30	<b>26.56</b>
CG + SS(T <sub>6</sub> )	5.00	5.87	7.20	7.90	<b>6.52</b>	6.16	7.13	10.53	12.57	<b>9.00</b>	20.50	23.70	27.70	36.67	<b>26.42</b>
CH + SS(T <sub>7</sub> )	5.67	6.33	7.83	8.53	<b>7.09</b>	7.54	8.23	12.20	14.60	<b>10.64</b>	24.11	24.97	29.93	41.07	<b>30.02</b>
CI + SS (T <sub>8</sub> )	4.87	5.60	7.27	7.57	<b>6.33</b>	5.63	6.33	10.77	12.63	<b>8.84</b>	19.91	22.83	26.70	34.30	<b>25.94</b>
CL + SS(T <sub>9</sub> )	5.07	5.53	7.03	8.00	<b>6.41</b>	6.12	7.03	11.43	12.90	<b>9.37</b>	22.09	24.10	26.87	35.23	<b>27.07</b>
CM + S(T <sub>10</sub> )	4.67	5.20	6.03	6.40	<b>5.58</b>	5.69	5.60	9.03	13.10	<b>8.36</b>	20.49	24.43	25.17	32.60	<b>25.67</b>
CO+ S(T <sub>11</sub> )	4.90	5.47	6.53	7.47	<b>6.09</b>	5.91	6.50	10.70	14.70	<b>9.45</b>	21.84	23.80	26.47	34.70	<b>26.56</b>
<b>Mean</b>	<b>4.97</b>	<b>5.58</b>	<b>6.92</b>	<b>7.66</b>		<b>6.11</b>	<b>6.82</b>	<b>10.62</b>	<b>13.03</b>		<b>21.64</b>	<b>24.22</b>	<b>27.22</b>	<b>35.27</b>	
	LSD(P=0.05);Treatment =0.399									= 0.892	= 1.947				
	Month = 0.2408									= 0.5379	= 1.174				
	Treatment * Month = 0.7985									= 1.7840	= 3.895				

CA = EFB + POME

CB = EFB + PKC + CH + WATER;

CC = EFB + POME +MF;

CD = EFB + PKC + WATER

CE = EFB + PKC + CH + POME;

CG = EFB + PKC + CH + PW+WATER;

CH = EFB + PKC + CH + PW +POME

CI = EFB + PKC + RP +POME;

CJ = EFB + RP +POME

CK = EFB + PKC + RP + CH + POME

CL = EFB + PKC + POME;

CM = EFB + W

Table 4.9 b: Effect of Compost Treatments on the Mean Seedling Height and Bole Diameter of OPRI Oil Palm Seedlings at 7 Months

Parameters Treat / months	Mean seedling height (cm)				Mean	Mean bole diameter (mm)				Mean
	4M	5M	6M	7M		4M	5M	6M	7M	
CA + SS(T <sub>1</sub> )	27.31	30.67	36.33	44.33	<b>34.66</b>	10.63	13.73	18.20	23.83	<b>16.60</b>
CC + SS(T <sub>2</sub> )	28.49	32.33	37.40	45.53	<b>35.94</b>	9.09	13.50	18.57	26.20	<b>16.84</b>
CD + SS(T <sub>3</sub> )	28.37	32.57	38.30	48.33	<b>36.89</b>	12.12	16.50	21.10	26.30	<b>19.01</b>
CE + SS(T <sub>4</sub> )	30.46	34.43	39.87	50.00	<b>38.69</b>	11.67	16.83	21.37	27.67	<b>19.38</b>
F + SS (T <sub>5</sub> )	26.75	31.10	36.60	43.00	<b>34.36</b>	8.39	13.03	17.00	24.63	<b>15.76</b>
CG + SS(T <sub>6</sub> )	27.83	31.17	36.37	47.10	<b>35.38</b>	12.00	14.50	19.93	24.87	<b>17.62</b>
CH + SS(T <sub>7</sub> )	32.18	32.53	42.93	54.83	<b>40.62</b>	13.78	16.80	24.40	28.93	<b>20.98</b>
CI + SS (T <sub>8</sub> )	25.26	29.73	36.60	45.13	<b>34.18</b>	10.57	14.57	20.47	25.33	<b>17.73</b>
CL + SS(T <sub>9</sub> )	28.06	30.93	38.63	47.17	<b>36.20</b>	10.38	14.53	20.47	25.90	<b>17.82</b>
CM + S(T <sub>10</sub> )	26.61	22.80	34.37	44.00	<b>31.94</b>	10.30	12.23	15.37	23.53	<b>15.36</b>
CO+ SS(T <sub>11</sub> )	27.40	30.47	36.30	45.27	<b>34.86</b>	9.74	13.60	17.67	24.83	<b>16.46</b>
<b>Mean</b>	<b>27.98</b>	<b>30.79</b>	<b>37.61</b>	<b>46.79</b>		<b>10.72</b>	<b>14.53</b>	<b>19.50</b>	<b>25.64</b>	

LSD(P=0.05); Treatment = 2.462  
 Month = 1.485  
 Treatment \* Month = 4.924

= 1.385  
 = 0.835  
 = 2.769

CA = EFB + POME

CC = EFB + POME + MF

CD = EFB + PKC + WATER

CE = EFB + PKC + CH + POME

F = Flanamite

CG = EFB + PKC + CH + PW + WATER

CH = EFB + PKC + CH + PW + POME

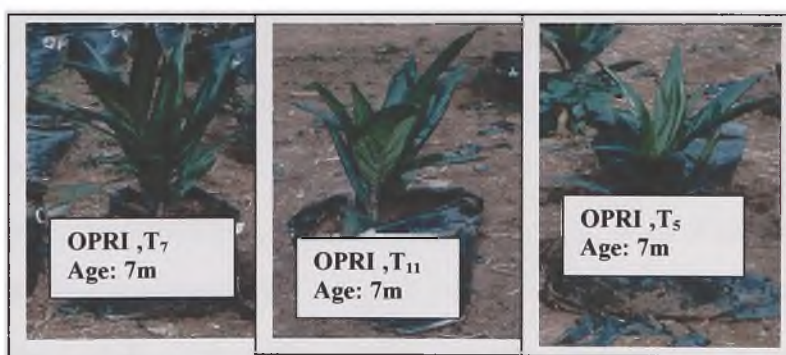
CI = EFB + PKC + RP + POME

CL = EFB + PKC + POME

CM = EFB + WATER

CO = NPK

NB : SS denotes subsoil.

Plate 4.11: Effect of Compost (T<sub>7</sub>), NPK (T<sub>11</sub>) Flanamite (T<sub>5</sub>) on OPRI Oil Palm Seedlings

#### 4.4.2 Effect of Compost Treatment on Number of Leaves, Leaf Width and Length, Seedling Height and Bole Diameter of La Mé Oil Palm Seedlings

*Mean number of leaves:* - Seedlings from the compost treatments showed highest mean number of leaves compared to NPK (T<sub>11</sub>) or Flanamite (T<sub>5</sub>) and was significant. Among the compost treatments T<sub>3</sub> recorded the highest mean number of leaves whilst T<sub>1</sub> recorded the least (Table 4.10a).

*Mean leaf width:* No significant difference in leaf width was observed among the compost treatments. The leaf widths of all the compost treatments were significantly higher than the NPK (T<sub>11</sub>) and Flanamite (T<sub>5</sub>). In the compost treatments, highest mean leaf width was observed in T<sub>3</sub> and the lowest in T<sub>2</sub>.

*Mean leaf length:* The mean leaf length of seedlings from the compost treatments was significantly higher than the NPK (T<sub>11</sub>) and the Flanamite (T<sub>5</sub>). Among the compost treatments, T<sub>3</sub> was significantly higher than the other compost treatments (Table 4.10a).

*Mean seedling height:* - Seedling height from compost treatments was also significantly different from the control (T<sub>11</sub>) or the Flanamite (T<sub>5</sub>). Apart from treatment T<sub>3</sub> which recorded the highest mean height there were no significant differences in seedling height among the compost treatments. The order of seedling height was as follows: T<sub>3</sub>>T<sub>8</sub> >T<sub>9</sub> >T<sub>2</sub>>T<sub>1</sub>>T<sub>11</sub>>T<sub>5</sub>

*Mean bole diameter:* Mean bole diameters of seedlings from compost treatments were significantly higher than the NPK (T<sub>11</sub>) or the Flanamite (T<sub>5</sub>). Similarly compost treatments T<sub>2</sub>, T<sub>3</sub>, T<sub>8</sub> and T<sub>9</sub> were also significantly higher than T<sub>1</sub> (Table 4.10 b). The ranking of bole diameter is as follow: T<sub>2</sub>>T<sub>3</sub> >T<sub>8</sub> >T<sub>9</sub>>T<sub>1</sub>>T<sub>11</sub>>T<sub>5</sub>

Table 4.10a: Effect of Compost Treatments on the Mean Number of Leaves, Leaf Width and Length of La Mé Oil Palm Seedlings

Parameters Treat / months	Mean number of leaves					Mean leaf width (cm)					Mean leaf length (cm)				
	4M	5M	6M	7M	Mean	4M	5M	6M	7M	Mean	4M	5M	6M	7M	Mean
CA + S(T <sub>1</sub> )	4.90	6.40	8.10	8.87	7.07	6.14	7.60	11.77	14.00	9.88	22.32	30.07	31.30	38.53	30.55
CC + SS(T <sub>2</sub> )	5.23	7.00	8.40	9.00	7.41	6.17	7.13	11.47	14.20	9.74	23.15	24.93	32.53	38.53	29.79
CD + SS(T <sub>3</sub> )	5.17	7.00	8.53	9.20	7.48	7.15	8.27	11.90	13.43	10.19	25.41	29.10	33.30	40.17	31.99
F + SS(T <sub>5</sub> )	3.60	4.53	5.70	6.57	5.10	3.00	3.80	7.30	8.53	5.66	14.33	18.70	20.07	27.23	20.08
CI + SS(T <sub>8</sub> )	5.00	7.00	8.67	9.10	7.44	6.52	7.77	11.53	13.57	9.85	24.17	26.70	32.20	38.83	30.48
CL + SS(T <sub>9</sub> )	5.00	7.10	8.40	9.13	7.41	6.54	7.97	11.00	14.00	9.88	23.43	26.33	31.53	37.67	29.74
CO + SS (T <sub>11</sub> )					5.64					7.00					22.56
<b>Mean</b>	<b>4.71</b>	<b>6.34</b>	<b>7.67</b>	<b>8.45</b>		<b>5.56</b>	<b>6.72</b>	<b>10.59</b>	<b>12.58</b>		<b>21.53</b>	<b>25.14</b>	<b>29.33</b>	<b>35.54</b>	
LSD(P=0.05); Treatment = 0.312										= 0.535					= 1.727
Month = 0.236										= 0.405					= 1.306
Treatment * Month = 0.624										= 1.070					= 3.454

CA = EFB + POME

CC = EFB + POME + MF

CD = EFB + PKC + WATER

CE = EFB + PKC + CH + POME

F = Flanamite

CG = EFB + PKC + CH + PW + WATER

CH = EFB + PKC + CH + PW + POME

CI = EFB + PKC + RP + POME

CL = EFB + PKC + POME

CM = EFB + WATER

CO = NPK (Control)

Table 4.10 b: Effect of Compost Treatments on the Mean Seedling Height and Bole Diameter of La Mé Oil Palm Seedlings

Parameters Treat / months	Mean seedling height (cm)					Mean bole diameter (mm)				
	4M	5M	6M	7M	Mean	4M	5M	6M	7M	Mean
CA + S(T <sub>1</sub> )	29.35	30.73	40.53	49.93	<b>37.64</b>	11.13	15.53	22.67	30.40	<b>19.93</b>
CC + SS(T <sub>2</sub> )	29.65	32.63	43.60	50.23	<b>39.03</b>	13.42	18.50	25.77	32.83	<b>22.63</b>
CD + SS(T <sub>3</sub> )	33.06	35.73	45.03	52.67	<b>41.62</b>	13.75	18.23	25.93	31.30	<b>22.30</b>
F + SS(T <sub>5</sub> )	18.01	23.10	27.60	33.63	<b>25.59</b>	5.61	8.67	13.07	18.27	<b>11.40</b>
CI + SS(T <sub>8</sub> )	31.63	32.17	43.87	51.03	<b>39.68</b>	12.48	17.43	26.43	31.80	<b>22.04</b>
CL + SS(T <sub>9</sub> )	27.39	34.87	42.87	51.17	<b>39.07</b>	13.22	18.77	26.07	29.10	<b>21.79</b>
CO + SS(T <sub>11</sub> )	23.12	25.90	31.47	36.03	<b>29.13</b>	7.02	9.90	15.03	19.37	<b>12.83</b>
<b>Mean</b>	<b>27.46</b>	<b>30.73</b>	<b>39.28</b>	<b>46.39</b>		<b>10.95</b>	<b>15.29</b>	<b>22.14</b>	<b>27.58</b>	
LSD(P=0.05); Treatment = 2.153						= 1.377				
Month = 1.628						= 1.041				
Treatment * Month = 4.307						= 2.754				

CA = EFB + POME

CC = EFB + POME + MF

CD = EFB + PKC + WATER

CE = EFB + PKC + CH + POME

F = Flanamite

CG = EFB + PKC + CH + PW + WATER

CH = EFB + PKC + CH + PW + POME

CI = EFB + PKC + RP + POME

CL = EFB + PKC + POME

CM = EFB + WATER

CO = NPK (Control)

Plate 4.12: Effect of Compost (T<sub>2</sub>), NPK (T<sub>11</sub>) and Flanamite (T<sub>5</sub>) on La Mé Oil Palm Seedlings

#### 4.4.3 Comparison of Growth Performance between OPRI and La Mé Oil Palm Seedlings

*Number of leaves:* -Significant increase in number of leaves was observed in La Mé oil palm seedlings over OPRI seedlings in compost treatments (Table 4.11). Conversely, OPRI seedlings from NPK treatment (T<sub>11</sub>) showed significant advantage

in mean number of leaves over La Mé seedlings in the same inorganic treatment. Also, the mean number of leaves of both La Mé and OPRI seedlings in each of the compost treatments T<sub>3</sub>, T<sub>8</sub>, T<sub>9</sub> and T<sub>2</sub> was higher than seedlings from the NPK (T<sub>11</sub>) and Flanamite (T<sub>5</sub>).

*Leaf width:* - La Mé seedlings recorded highest mean leaf width over OPRI seedlings in the compost treatments. Also, leaf widths of La Mé seedlings from treatment T<sub>1</sub> and T<sub>8</sub> were significantly higher than OPRI seedlings. On the other hand, OPRI seedlings in treatments T<sub>5</sub> and T<sub>11</sub> recorded significantly higher mean leaf width compared to La Mé seedlings.

*Leaf length:* - La Mé seedlings from compost treatments recorded significantly higher leaf length over OPRI seedlings. Conversely, OPRI seedlings from treatment T<sub>11</sub> and T<sub>5</sub> recorded higher mean leaf length over La Mé seedlings (Table 4.11).

*Seedling height:-* Mean heights of La Mé seedlings from the compost treatments were significantly higher than for OPRI seedlings. On the other hand, mean height of OPRI seedlings from treatments T<sub>11</sub> and T<sub>5</sub> were significantly higher than La Mé seedlings.

*Bole diameter-*This followed the same trend as in seedling height (Table 4.11).

Table 4.11: Comparing Mean Number of Leaves, Leaf Width, Length, Seedling Height and Bole Diameter of OPRI and La Mé Oil Palm Seedlings at 7 Months

Treatment	Variety	Mean number of leaf (cm)	Mean leaf width (cm)	Mean leaf length (cm)	Mean seedling height (cm)	Mean bole diameter(mm)
CA+SS (T <sub>1</sub> )	La Mé	7.067	9.877	30.55	37.64	19.93
	OPRI	5.692	7.805	26.06	34.66	16.60
CC +SS(T <sub>2</sub> )	La Mé	7.408	9.743	29.79	39.03	22.63
	OPRI	6.242	8.973	27.12	35.94	16.84
CD+SS (T <sub>3</sub> )	La Mé	7.475	10.187	31.99	41.62	22.30
	OPRI	6.577	9.670	27.78	36.89	19.01
CI+SS (T <sub>4</sub> )	La Mé	7.442	9.847	30.48	39.68	22.04
	OPRI	6.325	8.842	25.94	34.18	17.74
CL +SS (T <sub>5</sub> )	La Mé	7.408	9.877	29.74	39.07	21.79
	OPRI	6.408	9.372	27.07	36.20	17.82
CO +SS (T <sub>11</sub> )	La Mé	5.637	7.000	22.57	29.13	12.83
	OPRI	6.087	9.453	26.69	34.86	16.46
F +SS (T <sub>6</sub> )	La Mé	5.100	5.657	20.08	25.59	11.40
	OPRI	6.096	9.014	26.56	34.36	15.77
LSD		0.3616	0.8543	1.970	1.454	1.454



Plate 4.13: Effect of Inorganic Treatment (T<sub>11</sub>) on OPRI and La Mé Seedlings



Plate 4.14: Effect of Compost Treatment ( $T_3$ ) On OPRI and La Mé Seedlings

#### 4.4.4 Root Volume of OPRI Oil Palm Seedlings

There were no significant differences in the fresh root volume of OPRI seedlings between the compost treatments and also the NPK ( $T_{11}$ ) or the Flanamite ( $T_5$ ). Meanwhile, treatments  $T_6$ ,  $T_7$ ,  $T_8$ ,  $T_4$ ,  $T_1$ ,  $T_2$  and  $T_3$  recorded higher root volume than  $T_{11}$  and  $T_5$  (Table 4.12). Root volume of treatments  $T_6$  and  $T_7$  were 3.74% and 1.33%, respectively, higher than  $T_8$ . Similarly,  $T_1$  was 21% higher than  $T_{10}$ , and  $T_4$  was 20.3% higher than  $T_9$ .

#### 4.4.5 Root Volume of La Mé Oil Palm Seedlings

La Mé seedlings in the compost treatments recorded higher root volume, between 25.7 ml/plant in  $T_2$  and 39.3 ml/plant in  $T_8$  (Table 4.12), all of which were significantly higher than the NPK,  $T_{11}$  (16.0 ml/plant) and  $T_5$  (13.7 ml/plant).

Table 4.12: Effect of Compost Treatment on Root Volume of OPRI and La Mé Oil Palm Seedlings at 7 Month

Treatment	Fresh Root volume (ml/plant)	
	OPRI seedlings	La Mé seedlings
CA + SS (T <sub>1</sub> )	38.33	38.33
CC + SS (T <sub>2</sub> )	37.33	25.67
CD + SS (T <sub>3</sub> )	35.33	38.33
CE + SS (T <sub>4</sub> )	38.33	*
F + SS (T <sub>5</sub> )	31.33	13.67
CG + SS (T <sub>6</sub> )	44.00	*
CH + SS (T <sub>7</sub> )	41.50	*
CI + SS (T <sub>8</sub> )	39.33	39.33
CL + SS (T <sub>9</sub> )	25.33	30.33
CM+ SS (T <sub>10</sub> )	25.33	*
CO + SS (T <sub>11</sub> )	31.33	16.00
Lsd	13.74	11.61

\* Not determined

CA = EFB + POME

F = Flanamite

CL = EFB + PKC + POME

CC = EFB + POME +MF

CG = EFB + PKC + CH + PW + WATER

CM = EFB +WATER

CD = EFB + PKC + WATER

CH = EFB + PKC + CH + PW +POME

CO = NPK

CE = EFB + PKC + CH + POME

CI = EFB + PKC + RP +POME

#### 4.4.6 Comparison of Fresh Root Volume of OPRI and La Mé Oil Palm Seedlings

*Root volume:* - Highest root volume was observed in both La Mé and OPRI seedlings in the compost treatments. No significant differences in root volume were observed among the compost treatments within La Mé and OPRI seedlings. However, the root volume of OPRI seedlings from the NPK (T<sub>11</sub>) and Flanamite (T<sub>5</sub>) treatments were significantly higher than for La Mé seedlings.

#### 4.4.7 Effect of Compost on Dry Matter Yield and Nutrient Uptake by Two Oil Palm Varieties (OPRI and *La Mé*)

##### (a) OPRI oil palm seedlings

###### *Dry matter yield*

The total dry matter yield (DMY) of treatment T<sub>7</sub> was the highest (33.38g/plant) followed by T<sub>4</sub> (28.55 g/plant) and T<sub>6</sub> (28.13g/plant). Treatment T<sub>5</sub> recorded the lowest DMY (Table 4.13). The DMY of T<sub>7</sub> was significantly higher than T<sub>11</sub> and T<sub>5</sub>. The DMYs of the leaves and bole diameter of treatment T<sub>7</sub> (17.27g/plant, 9.88g/plant) were higher than treatment T<sub>6</sub> (14.06 g/plant, 8.09 g/plant) and that of T<sub>4</sub> (13.47 g/plant, 8.46 g/plant). Conversely, DMY of the roots of T<sub>4</sub> (6.63 g/plant) was higher than that of T<sub>7</sub> (6.23 g/plant) and T<sub>6</sub> (5.98 g/plant) respectively.

###### *Nitrogen uptake*

The nitrogen uptake values for seedlings in the compost treatments, T<sub>7</sub>, T<sub>6</sub>, T<sub>2</sub>, T<sub>3</sub>, T<sub>8</sub> and T<sub>4</sub> were higher than that of NPK (T<sub>11</sub>) and Flanamite (T<sub>5</sub>) (Table 4.13). Among the compost treatments, the total nitrogen uptake in T<sub>7</sub> was the highest with T<sub>10</sub> being the lowest. No significant differences were observed among the following compost treatments: CA and CM, CD and CL, CH and CG, CE and CL. On other hand higher significant nitrogen was accumulated in the leaves (448.1 mg/plant) than in the bole + petiole (207.9 mg/plant) and the roots (125mg/plant)(Appendix 2).

###### *Phosphorus uptake*

Higher phosphorus uptake was observed in T<sub>7</sub> (172.6 mg/plant) seedlings followed by T<sub>6</sub> (133.2 mg/plant) and T<sub>4</sub> (111.7 mg/plant) (Table 4.13). The P uptake

in treatment T<sub>7</sub> seedlings was 21% higher than in T<sub>4</sub> and 13% higher than T<sub>6</sub>. Similarly, the P uptake by T<sub>7</sub> seedlings was two times more than that of T<sub>8</sub>. On the other hand, seedlings from the NPK treatment (T<sub>11</sub>) and the Flanamite (T<sub>5</sub>) recorded the lowest P uptake (71.0 and 72.6 mg/plant, respectively). Among the plant parts, higher P was accumulated in the leaves (43.6 mg/plant) followed by the bole + petiole (36.5 mg/plant) (Appendix 2). These were also significantly different from the amount accumulated in the roots at P (0.001).

#### *Potassium uptake*

Total K uptake values for OPRI seedlings from compost treatments T<sub>7</sub>, T<sub>4</sub> and T<sub>6</sub> were significantly higher than for the NPK (T<sub>11</sub>) and the Flanamite (T<sub>5</sub>) at P (0.05). Similarly, significant differences were observed among treatments T<sub>7</sub>, T<sub>4</sub> and T<sub>6</sub> (Table 4.13). The K contents in the different plant parts were significantly different. About 229.4 mg/plant K was accumulated in the leaves, 115.1 mg/plant K in the bole + petiole and 126.5 mg/plant K in the roots (Appendix 2). The relative accumulation of potassium in the roots, compared to phosphorus, calcium and others, was higher.

#### *Calcium uptake*

No significant differences were observed in Ca uptake among the compost, NPK and flanamite treatments. However, OPRI seedlings from compost treatments T<sub>4</sub>, T<sub>3</sub>, T<sub>9</sub>, T<sub>7</sub> and T<sub>2</sub> absorbed more Ca than the NPK (T<sub>11</sub>). Calcium accumulation values in different plant parts were significantly different at P (0.001). About 28.32 mg/plant Ca was accumulated in the leaves followed by the bole + petiole (7.37 mg/plant) and the roots (0.37 mg/plant) (Appendix 2).

Table 4.13: Effect of Compost on Dry Matter Yield and Nutrient Uptake of OPRI Oil Palm Seedlings at 7 Months

Treatment	Total Dry matter yield (g/plant)	N mg/plant	P mg/plant	K mg/plant	Ca mg/plant	Mg mg/plant
CA+SS(T <sub>1</sub> )	24.48	726.61	86.95	489.97	31.55	95.38
CC+SS(T <sub>2</sub> )	25.81	836.76	95.83	442.63	35.98	82.74
CD+SS(T <sub>3</sub> )	24.21	830.27	85.37	398.37	43.04	76.07
CE+SS(T <sub>4</sub> )	28.55	799.41	111.66	603.10	47.07	105.96
F+SS (T <sub>5</sub> )	21.92	668.55	72.63	426.47	38.52	109.32
CG+SS(T <sub>6</sub> )	28.13	914.16	133.18	558.59	29.70	130.49
CH+SS(T <sub>7</sub> )	33.38	968.56	172.56	698.13	38.74	130.03
CI+SS(T <sub>8</sub> )	24.14	802.11	83.00	479.37	30.53	96.14
CL+SS(T <sub>9</sub> )	24.68	701.80	98.25	365.77	39.37	107.72
CM+SS(T <sub>10</sub> )	23.40	584.88	70.41	380.94	30.92	65.84
CO+SS(T <sub>11</sub> )	23.31	766.01	70.96	338.20	31.31	74.74
LSD	7.53	303.0	80.86	41.28	NS <sup>‡</sup>	41.28

CA = EFB + POME

CC = EFB + POME + MF

CD = EFB + PKC + WATER

CE = EFB + PKC + CH + POME

F = Flanamite

CG = EFB + PKC + CH + PW + WATER

CH = EFB + PKC + CH + PW + POME

CI = EFB + PKC + RP + POM

CL = EFB + PKC + POME

CM = EFB + WATER

CO = NPK

### Magnesium uptake

Highest Mg uptake among OPRI seedlings was observed in T<sub>6</sub> (130.5 mg/plant) and (T<sub>7</sub>) (130.0 mg/plant). Values for magnesium uptake in treatments T<sub>6</sub> and T<sub>7</sub> were significantly higher than for the NPK (T<sub>11</sub>) and compost treatments T<sub>2</sub>, T<sub>3</sub> and T<sub>10</sub> at P < 0.05. The uptake from treatment T<sub>6</sub> was 15% higher than for T<sub>8</sub>. The amount of Mg accumulated in the leaves (54 mg/plant) was significantly higher than the bole (32 mg/plant) and the roots (11.7 mg/plant) (Appendix 2).

<sup>‡</sup> No significant difference

***(b) La Mé oil palm seedlings******Dry matter yield***

Values of total dry matter yield for La Mé oil palm seedlings in the compost treatments were about three times higher and significantly different from the NPK ( $T_{11}$ ) and  $T_5$  at  $P < 0.001$ . Table 4.14. Higher dry matter yields were observed in treatments  $T_2$  and  $T_8$ . The Flanamite ( $T_5$ ) showed the lowest DMY. The DMYs of the leaves and roots of treatment  $T_8$  (17.82 g/plant, 6.43g/plant) were higher than treatment  $T_3$  (17.16 g/plant, 6.08 g/plant) and that of  $T_2$  (17.16 g/plant, 5.79 g/plant). Conversely, DMY of the bole diameter of treatment of  $T_2$  (14.75 g/plant) was higher than that of  $T_8$  (13.40 g/plant) and  $T_3$  (12.08 g/plant) respectively.

***Nitrogen uptake***

The total nitrogen uptake by the La Mé oil palm seedlings in compost treatments was significantly higher than the NPK ( $T_{11}$ ) and  $T_5$  at  $P < 0.001$ , Table 4.14. No significant difference was observed in the uptake among compost treatments. Highest N uptake was observed in treatment  $T_2$  (921 mg/plant) followed by  $T_1$  (915 mg/plant N) and  $T_3$  (819 mg/plant N). On the other hand, the total nitrogen values in different plant parts were significantly different. About 410.7mg/plant N was accumulated in the leaves, 176.9 mg/plant in the bole + petiole and 84.6 mg/plant in the roots (Appendix 2).

***Phosphorus uptake***

Significant difference was observed in the P uptake between compost treatments and the NPK ( $T_{11}$ ) and  $T_5$  at  $P < 0.001$  (Table 4.14). Highest P uptake was observed in  $T_2$  (166.1 mg/plant) followed by  $T_3$  (146.9mg/plant),  $T_8$  (142.3 mg/plant)

and T<sub>1</sub> (134.7 mg/plant). The amount of P in the leaves (50.2 mg/plant) was significantly higher than the bole + petiole (42.2 mg/plant) and the roots (18.6 mg/plant)(Appendix 2) .

#### *Potassium uptake*

Values for K uptake among compost treatments were as for other nutrients, significantly higher than for the NPK (T<sub>11</sub>) and T<sub>5</sub> at P < 0.001 (Table 4.14). Highest K was absorbed in T<sub>1</sub> (741 mg/plant) followed by T<sub>8</sub> (637 mg/plant). The amount of K accumulated in the leaves (234.8 mg/plant ) was higher and significantly different from the bole + petiole (117.6 mg/plant ) and the roots (95.1 mg/plant )(Appendix 2)

Table 4.14: Effect of Compost on Dry Matter Yield and Nutrient Uptake of La Mé Oil Palm Seedlings at 7 Months

<b>Treatment</b>	<b>Total dry matter yield (g/plant)</b>	<b>N mg/plant</b>	<b>P mg/plant</b>	<b>K mg/plant</b>	<b>Ca mg/plant</b>	<b>Mg mg/plant</b>
CA +SS(T <sub>1</sub> )	32.08	915.05	134.72	740.59	30.79	114.13
CC +SS(T <sub>2</sub> )	37.68	920.73	166.08	529.15	81.70	137.14
CD +SS(T <sub>3</sub> )	35.32	818.71	146.86	545.61	41.84	111.34
F +SS(T <sub>5</sub> )	9.85	311.09	38.89	171.77	18.29	33.68
CI +SS(T <sub>8</sub> )	37.65	764.50	142.32	636.96	91.57	182.41
CL +SS(T <sub>9</sub> )	32.06	750.68	116.90	454.10	72.29	131.07
CO+SS(T <sub>11</sub> )	12.58	224.80	31.21	148.15	26.95	45.36
LSD	9.66	274.9	45.84	217.8	20.28	53.17

#### *Calcium uptake*

Calcium uptakes in compost treatments T<sub>8</sub>, T<sub>2</sub> and T<sub>9</sub> in the La Mé seedlings were higher and significantly different from the NPK (T<sub>11</sub>) and T<sub>5</sub> at P < 0.001, Table 4.14. Similarly, treatments T<sub>8</sub>, T<sub>2</sub> and T<sub>9</sub> were also higher and significantly different

from compost treatments T<sub>1</sub> and T<sub>3</sub>. The amount of calcium in the leaves (234.8 mg/plant) was also significantly higher than in the bole + petiole (117.6 mg/plant) and the roots (95.1 mg/plant)(Appendix 2).

#### *Magnesium uptake*

Mean magnesium uptake among the compost treatments in La Mé seedlings were significantly higher than for the NPK (T<sub>11</sub>) or treatment (T<sub>5</sub>). Highest Mg uptake was observed in treatment T<sub>2</sub> (921 mg/plant) followed by T<sub>1</sub> (915 mg/plant) and T<sub>3</sub> (819 mg/plant). The amount of magnesium in the leaves (59.4mg/plant) was significantly higher than for the bole + petiole (39.5 mg/plant) and the roots (9.0mg/plant) ( Appendix 2).

#### **4.4.8 Comparison of Nutrient Uptake between OPRI and La Mé Oil Palm Seedlings**

##### *Dry matter yield s*

Significant differences were observed in the DMY among the seedlings. La Mé seedlings recorded higher and significant DMY over OPRI seedlings on compost treatments (Table 4.15). Conversely, OPRI seedlings from T<sub>11</sub> and T<sub>5</sub> gave significantly higher DMY than La Mé seedlings at  $P < 0.001$ .

##### *Nitrogen uptake*

Total nitrogen uptake values for La Mé seedlings from the compost treatments T<sub>1</sub>, T<sub>2</sub> and T<sub>9</sub> were higher than OPRI seedlings in corresponding treatments( Table 4.15). Conversely, values of N uptake by OPRI seedlings in

compost treatments T<sub>3</sub> and T<sub>8</sub>, the NPK (T<sub>11</sub>) and Flanamite (T<sub>5</sub>) were higher compared to their La Mé seedlings counterpart. OPRI seedlings from treatments, T<sub>11</sub> and T<sub>5</sub> absorbed 55 and 36% more nitrogen than La Mé seedlings from the same treatments.

#### *Phosphorus uptake*

Among the compost treatments, P uptake values for LaMé seedlings were higher and significantly different from the OPRI seedlings. Conversely, OPRI seedlings in treatments T<sub>11</sub> and T<sub>5</sub> absorbed higher and significantly ( P < 0.001) more P (Table 4.15).

#### *Potassium uptake*

The K uptake by La Mé seedlings from the compost treatments was higher than for OPRI seedlings (Table 4.15). The values were however not significantly different except for the low value recorded for treatment T<sub>1</sub>. On the other hand, K uptake by OPRI seedlings in the NPK (T<sub>11</sub>) and Flanamite (T<sub>5</sub>) treatments were significantly higher than in the La Mé seedlings.

#### *Calcium and magnesium uptake*

A similar trend as in K uptake was observed for calcium and magnesium uptake (Table 4.15). Significant higher Ca uptake was observed in La Mé seedlings on treatments T<sub>2</sub>, T<sub>8</sub> and T<sub>9</sub> as compared to OPRI seedlings from the same treatments. Magnesium uptake by La Mé seedlings on treatments T<sub>2</sub> and T<sub>8</sub> was significantly higher than for the OPRI seedlings.

Table 4.15: Comparing Total Dry Matter Yield and Nutrient Uptake of OPRI and La Mé Oil Palm Seedlings at 7 Months

Treatment	Variety	Total dry matter yield (g/plant)	N mg/plant	P mg/plant	K mg/plant	Ca mg/plant	Mg mg/plant
CA+SS(T <sub>1</sub> )	La Mé	32.08	915.05	134.72	740.59	30.79	114.13
	OPRI	24.48	726.61	86.95	489.97	31.55	95.38
CC +SS(T <sub>2</sub> )	La Mé	37.68	920.73	166.08	529.15	81.70	137.14
	OPRI	25.81	836.76	95.83	442.63	35.98	82.74
CD+SS (T <sub>3</sub> )	La Mé	35.32	818.71	146.86	545.61	41.84	111.34
	OPRI	24.48	830.27	85.37	398.37	43.04	76.07
F +SS (T <sub>5</sub> )	La Mé	9.85	311.09	38.89	171.77	18.29	33.68
	OPRI	21.92	668.55	72.63	426.47	38.52	109.32
CI +SS (T <sub>8</sub> )	La Mé	37.65	764.50	142.32	636.96	91.57	182.42
	OPRI	24.14	802.11	83.00	479.37	30.53	96.14
CL +SS (T <sub>9</sub> )	La Mé	32.06	750.68	116.90	454.10	72.29	131.07
	OPRI	24.68	701.80	98.25	365.77	39.37	107.72
CO +SS (T <sub>11</sub> )	La Mé	12.58	224.80	31.21	148.15	26.95	45.36
	OPRI	23.31	766.01	70.96	338.20	31.31	74.74

#### 4.5 SOCIETAL PERCEPTION AND OPINION ON COMPOSTING AND THE USE OF COMPOST FOR AGRICULTURAL PURPOSES

##### 4.5.1 Opinion and Perception of Oil Palm Processing Managers about Composting

Out of the twenty-two managers interviewed only six had heard of composting, with only two of them admitting to having the technical know-how in composting. Thus about 90% of the oil palm processing managers residing in the Kwaebibirem district had no knowledge of composting. Meanwhile, 96% of them responded yes to go into composting of the oil palm residues provided training and financial assistance could be offered to them (Figure 4.12 ).

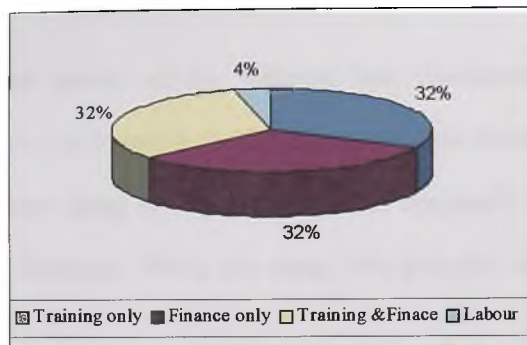


Figure 4.12: Request of Palm Oil Processing Mills

#### 4.5.2 Perception and Willingness of the Public to Use Compost

Perception of potential compost users was also analysed in order to find out whether there will be a market for the compost that will be produced by the processing mills. The evaluation covered 100 rural farmers from the Kwaebibirem District, 50 urban vegetable growers and 50 “wayside” floriculturists in the Greater Accra Municipality. Two hundred farmers were interviewed and used for the analysis.

The study first assessed the various soil ameliorants being used by the respondents. Out of hundred rural farmers interviewed, 65% used inorganic fertilizer (mainly NPK) to grow their crops. The remaining 35% did not apply any chemical to the soil. On the other hand the urban vegetable growers and wayside floriculturists in the Accra metropolis use both organic and inorganic fertilizers to improve soil fertility. Out of fifty urban vegetable growers interviewed, 52% of them use poultry droppings, 32% use inorganic fertilizers and 16% use cow dung. This is different from the wayside floriculturists where 42% out of fifty people interviewed use cow

dung, 26% use inorganic fertilizers, 20% use compost and 12% use poultry droppings.

The combined results of the different soil ameliorants being used by respondents are shown in Figure 4.13. The use of inorganic fertilizers is 47% whilst organic fertilizer (cow dung, poultry droppings and compost<sup>§</sup>) is 36%. Out of the 36% of the organic fertilizer, 15% is cow dung, 16% is poultry droppings and 5% is compost.

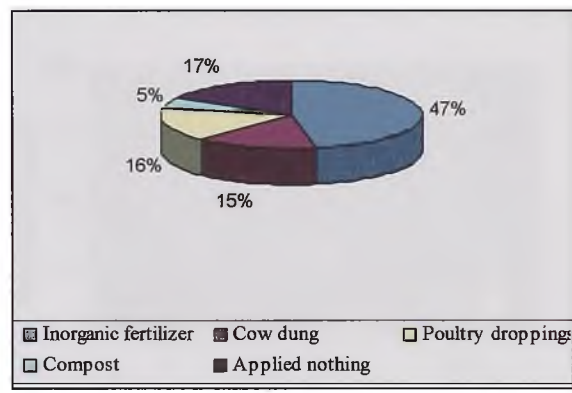


Figure 4.13 Percentage Proportion of Different Nutrients Being Used

The reasons given for the high use of poultry manure and cow dung were that they are easy to get in large quantities, cheap (price for tractor load is between ₵30,000 to ₵50,000), and support successful plant growth. Respondents however assigned low use of compost to unawareness, lack of technical know-how and space for composting, and longer time taken for compost to mature.

Respondents' perception and willingness to the use of compost as soil nutrient source revealed that ninety-two percent (92%) perceived compost as good source of soil nutrients that ensures successful plant growth and were willing to buy and use it

<sup>§</sup> The compost used was prepared from dead leaves. It has a low nutrient value as compared to the one prepared from the agricultural and agro-industrial residues.

provided they will be supplied regularly. Four percent (4%) were uncertain whilst 4% said no because they were not sure compost could do better than the poultry and cow dung that they had been using. Respondents preparedness to be trained in composting and education on the importance of compost was also assessed and reported in Figure 4.14.

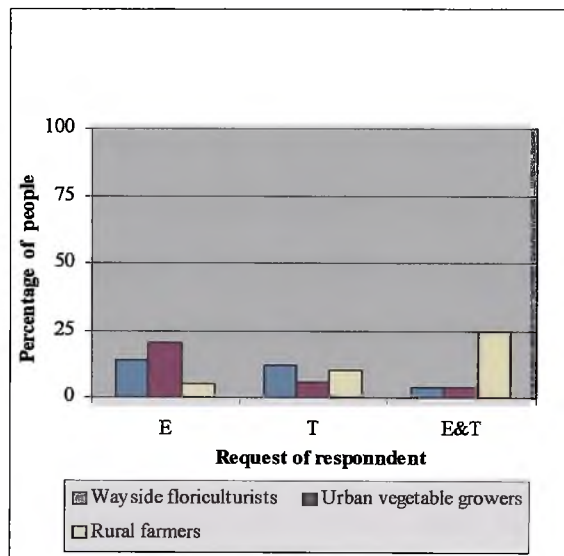


Figure 4.14: Request Made By Potential Compost Users (E, Stand for Education and T, For Training)

## CHAPTER 5: DISCUSSION

### 5.1 CHARACTERISATION OF RESIDUES GENERATED BY OIL PALM INDUSTRY, IMPACT ON THE ENVIRONMENT AND ALTERNATIVE TREATMENT

#### 5.1.1 -5.1.4 Oil Palm Mills, Milling Process, Types and Amounts of Residues Generated and Chemical Characteristics

The common wastes generated by the twenty-two Mills are as a result of the similar common processes they go through which include the softening of fresh fruits; separation of individual fruits from bunches; pressing out of oil; clarification and purification of oil (Figure 4.1 and 4.2). On the other hand the large amount of EFB, POME (Table 4.2), MF and PKC generated by GOPDC (a large scale Mill) is due to the high capacity of the Mill (48 tons/hr) with an extraction rate of about 20% of oil, and in addition a palm kernel crushing plant of 45 tons/day as compared to 17% extraction rate of the small scale mills (GOPDA, 2000). The low pH and high nutrient content of the residues (Table 4.4) is an indication that the residues might be a potential threat to the environment if not managed properly.

#### 5.1.5 Comparison of the Chemical Composition of POME Generated by the Large Scale and Small Scale Oil Processing Mills

The low pH, high electrical conductivity, total dissolved solids, COD, BOD and oil content of the POME generated by the small scale Mills are outside the limits set by the Ghana Environmental Protection Agency (EPA) waste water quality guidelines for discharges into water bodies, as well as the Malaysian Standards for palm oil mill effluent for watercourse discharge reported by Maheswaran (1997)(Table 4.5). The low pH, high electrical conductivity, total dissolved solids,

COD, BOD and oil content of the POME might lead to eutrophication and its associated problems (Maheswaran, 1997).

However, although, the treated POME from GOPDC also recorded higher pH, low electrical conductivity, total dissolved solids, COD, BOD and oil content than the small scale, these values were still above Environmental Protection Agency (EPA) wastewater quality guidelines for discharges into water bodies but within the Malaysian standards\* for palm oil mill effluent for watercourse discharge except for suspended solids and oil content. This agrees with an environmental impact assessment report submitted to the company (EPA, 2000).

#### **5.1.6 Methods Being Used by the Small and Large Scale Mills to Treat the Palm Residues**

.The low pH, high electrical conductivity, high total dissolved solids, COD, BOD and oil content of the untreated POME (Table 4.5) indicate that untreated POME is a threat and will pollute the environment.

Conversely, the anaerobic digestion of the POME (Plate 4.6) being practiced by the large scale Mill seems effective, but it requires technical skills and management commitment (Gert, 2002) beyond the capacity of the small scale processing mills. Similarly the use of the raw EFB and MF as mulch on plantations, and the ash as fertilizer might easily enhance leaching of nutrients into nearby water bodies during and after rainfalls (SMARTRI and CIRAD-CP, 2001).The ash is also corrosive and may pose problems to the environment and the health of the people

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\* *Malaysian standards were used because Ghana did not have standards or guidelines for palm oil mill effluent (POME).*

(Tam et al., 1983). Burning of the EFB and MF might also cause atmospheric pollution (Henson, 1994). Consequently, this practice has been banned in newly constructed mills in oil palm producing countries (Suhaimi and Ong, 2001).

### **5.1.7 Impact of Palm Residues on Water Bodies near Small Scale Oil Processing Mills**

The pH values of the water bodies near the small scale oil processing mills (Table 4.6 ) fell within the pH range 6.5-8.5 for water bodies and for fresh waters in the deciduous forest (Biney, 1982). This does not imply that the low pH of the untreated POME has no effect on the rivers. Hodgson (2002) assigned the pH of the river to the effect of the terrain of the river beds. However, from this study it could also be pointed out that potassium salts that might be leached and washed from accumulated EFB and ash of burnt EFB and MF from farms and Mills may have a neutralizing effect on the low pH of the POME (SMARTRI and CIRAD-CP, 2001 ). The high values of DO, BOD, COD and TSS above the acceptable limits for fresh water are also an indication that the water bodies may be polluted with high organic materials. Locally, Biney (1982) has rated pollution of water bodies as follows: BOD for unpolluted water bodies and those recovering from pollution is less than 4.0mg/l; water bodies with BOD between 4.0-12.0mg/l are described as doubtful and of poor quality whilst those with values greater than 12.0mg/l are grossly polluted.

Kadewa upstream to Kadewa downstream recorded very high values of BOD between 10.8 mg/l to 14.4 mg/l which give an indication of gross pollution. Kadewa upstream and downstream are areas in Kade where there is a high concentration of the small scale mills. Untreated POME is discharged from University of Ghana Agricultural Research Station (UGARS ) and Damang Mills into the environment, this is washed into a river which joins Kadewa stream. The Kadewa stream further

runs close to Awoyo No. 1, No.2 and No.3 Mills at Kade where most of the untreated POME occurs, and MF and EFB are dumped into the environment (Plate 4.7) . Although all the areas recorded low values for DO below the natural background range for freshwater, that of Kadewa upstream to Kadewa downstream recorded very low values of DO (0.93-1.23mg/l).

Mining, which is another major contributor to pollution of water bodies within the study area, is only practiced along River Birim which is at the lower course of Kadewa and Kadepon streams. This can therefore not confer polluting properties to water upstream, where water samples were taken. Therefore the contamination of the water bodies near the mills can be attributed directly to the discharge of the untreated POME into the watercourse, and also poor solid palm residue management practices. The high values of the chemical characteristics of POME (Table 4.5 ) coupled with the large quantity of wastes generated (Table 4.2) support this assertion. The consequence of such concentrated POME on water bodies is eutrophication (Maheswaran, 1997). The low BOD (5.6 mg/l) and high DO (8.58 mg/l) observed in Birim River (Kade) far down stream might be due to the long distance from the sites and the large volume of the river and its turbulent flow.

Currently about 250,000 hectares of land are under oil palm cultivation in Ghana (Table 4.3). When in full production this will generate about 632,500 metric tonnes of EFB and 1,402,500m<sup>3</sup> of POME. The Presidential Special Initiative (PSI) on oil palm is expected to bring an additional 100,000 hectares of land under oil palm cultivation by 2007. This will generate about 974,050 metric tonnes of EFB and 2,159,850 m<sup>3</sup> of POME in 2007. In the long term (over ten years) a total of 585,000 hectares will be brought under cultivation. This is expected to generate about 1,480,050 metric tonnes of EFB and 3,281,850 m<sup>3</sup> of POME. This implies that sustainable waste disposal methods have to be found otherwise most of the water

bodies in the areas earmarked for the cultivation of oil palm under the PSI on oil palm will be under pollution threat. Water is second to oxygen in supporting life. Water is one of the greatest needs of society, suggesting that the future of such communities and the various life forms in these water bodies are threatened. Efficient method of waste management is therefore needed to treat current and future waste. There is therefore the need to look for a sustainable, environmentally friendly and efficient alternative treatment method to solve the problem since the methods being practised are ineffective. The pond system being practised by GOPDC is also very expensive, besides requiring expertise and skills (Gert, 2002).

## 5.2 BIOCHEMICAL CHANGES DURING COMPOSTING OF THE DIFFERENT ORGANIC WASTES AND EVALUATION OF COMPOST MATURITY

### 5.2.2 Composting Process and Evaluation of Compost Maturity

#### *Temperature*

Generally the temperature of the different compost treatments increased during the first 8 weeks up to a maximum and then decreased gradually to a minimum around the 14<sup>th</sup> week. Thereafter the temperature remained constant till the end of composting around 138 days. The compost at this stage was considered matured because the temperature remained constant after the 14<sup>th</sup> week (Stickelberger, 1975). Temperature evolution according to Feinstein et al. (1980) is a reflection of microbial activity in the composting process. This implies that microbial activity in treatment CA and CC (Figure 4.5) was higher in the first week but slowed down after the first week. This might be due to the fibrous nature of EFB which makes it more crystalline when dried and difficult to decompose (Suhaimi and Ong, 2001). Or it is also possible that the N source might have been initially low. It may therefore be advisable to add water to POME when it is very dense, and increase N sources in such composting mixtures.

#### *Carbon dioxide (CO<sub>2</sub>) evolution (microbial activity)*

Carbon dioxide evolution provides a measure of the response of microbial activity (respiration) to diurnal variations in temperature, moisture, and differences in compost treatments or substrates. The general decrease in CO<sub>2</sub> evolution with time of the different compost treatments over the 18 weeks (Figure 4.6) might be due to the decrease in microbial activities as a result of decrease in the amount of biodegradable

materials. The higher CO<sub>2</sub> evolution values obtained in treatment CI (23.5 mgg<sup>-1</sup>d<sup>-1</sup>) and CE (22.7 mgg<sup>-1</sup>d<sup>-1</sup>) at days 7 and 50 might be due to type of substrates. It appears that the substrates (EFB, POME, PKC and cocoa pod husk or Rock phosphate) were more biodegradable at days 7 and 50 thereby enhancing the activities of the microorganisms. According to Ayuso (1996), microbial activity to a large extent depends on the nature of organic matter added to soil or the compost mixtures. The slowed microbial activities at days 7 and 50 in treatments CA and CC might also be attributed to the large amount of fibrous materials with very high initial C/N ratio (Table 4.8a). According to Sharma et al. (1997), the presence of excessive carbon in composting materials slows microbiological activities. In this experiment CO<sub>2</sub> evolution was less than 2.00 mgg<sup>-1</sup>d<sup>-1</sup> indicates that compost is matured.

Except for treatment CE, a very strong correlation ( $r = 0.7$ ) was observed between carbon dioxide evolution and temperature changes in all the treatments. For example in treatment CA and CI the increase in CO<sub>2</sub> evolution was also reflected in increase in temperature (Figure 4.5). In treatment CA temperature increased between the 7<sup>th</sup> to the 12<sup>th</sup> weeks. This is so because microbial activity between those periods was higher (Figure 4.6) and since the energy released from decomposition of organic materials is given off as heat, it will cause a rise in temperature within the piles till a certain limit is reached.

#### *C:N ratio*

According to Mote and Griffis (1980) the suitable carbon: nitrogen (C/N) ratio of initial material for composting ranged between 26:1 and 30:1. This will ensure that carbon and nitrogen are present in adequate proportion for microbial growth and decomposition of waste (Guar, 1980; Bishop and Godfrey, 1983). This

means that the carbon: nitrogen ratio of the initial mixtures used in the study was adequate for the successful composting to take place (Table 4.8a).

By the 50<sup>th</sup> day all the compost mixtures recorded a C:N ratio less than 15 except treatment CA which was 18.5. This agrees with open compost prepared with EFB, POME and manure (Suhaimi and Ong, 2001). C:N ratios lower than 20 for municipal compost have been used as an indicative of an acceptable maturity in the final product (Inbar et al., 1990; Golueke, 1981; Cardenas and Wang, 1980). Similarly, Polprasert (1996) also pointed out that material with high C:N ratios can be used as an indicator of maturity when the ratio is between 15-20. Since the C:N ratios of the compost samples were below 15 at 50 days it suggests that the compost treatments were matured to be used. However, the germination index was less than 100, and none of them had germination index (GI) more than 45% (Table 4.8a); treatment CA recorded 25%, CC 43%, CE 45% and CI 40%. According to Innanotti et al. (1993), GI of less than 100% suggests that the compost was immature and may be phytotoxic. This might explain the poor germination of tomato seeds in compost samples at 50 days. The low C:N ratio recorded from the 50th day onwards, may therefore not imply that the composts were matured but may be a reflection of the relatively nitrogen richness of the composting materials (Table 4.8a). This agreed with the report made by Morel et al. (1985) that C:N ratios below 20 are often found in materials not yet matured, due to the relative N-richness of the composting materials. According to Polprasert (1996), if the C:N ratio of the initial composting material is around 44.3, the mixture is matured when the C:N ratio is around 12.5. The results obtained is at variance with Polprasert (1996), because at day 50, treatment CC which had initial C:N ratio of 44.3 and had reached 12.5, was not matured according to GI. This agrees with Hirai et al. (1983) that C: N ratio of compost cannot be used as an absolute indicator of the state of maturity. The C: N

ratios found in well-composted materials vary considerably, due to the type of the original material.

### *pH*

The initial pH of all the treatments was within the optimum range for composting (5.6-6.1) (Bertoldi et al., 1983; Miller, 1992; Polprasert, 1996). The low initial pH at the onset of the composting process (Figure 4.8) might be due to the action of the microorganisms on the most labile organic matter fraction (e.g. carbohydrates), leading to the release of carbon dioxide and organic acids (Bernal et al., 1998a). The rise in pH up to 8.3 might be due to elimination of carbon dioxide (Sharma et al., 1997), and loss of ammonium through volatilization as a result of high atmospheric temperatures (32.2-34.8° C) prevailing during the composting process (Table 4.8a). The fall in pH values at the end of composting process might presumably be due to the loss of organic compounds produced during composting and the resultant increase in the proportion of mineral constituents of the residues (Garcia 1992).

The fall in pH of pile CA at 50 days might be due to formation of organic acids or the increase in temperature between the 5<sup>th</sup> to 12<sup>th</sup> weeks (Figure 4.5) which might have caused more ammonia to be lost through volatilisation. The same explanation might hold for treatment CE between 6<sup>th</sup> to 9<sup>th</sup> week, and CI between 9<sup>th</sup> to 13<sup>th</sup> weeks. With the exception of CE the pH of all the compost treatments began to decrease rapidly after 78 days. The decrease was in pace with NH<sub>3</sub> loss (Figure 4.9). By the end of the process, the pH rose to nearly neutral (6.4-7.9) which is an indication of stabilised material (Sesay et al., 1997). From the results it could be seen that there is a positive correlation ( $r = 0.4$ ) between pH and germination index in determining compost maturity. For example treatment CC between 78 and 98 days

recorded pH values of 8.7 and 8.3 with corresponding GI between 75- 95% (Table 4.8b). CI also recorded 7.0 and 7.5 between the 50<sup>th</sup> and 78th day with GI equal to 95%. These agree with the report of Jiménez and Garcia (1992), that compost treatment with alkaline pH for 24 hrs or more may be considered sufficiently matured . Thus pH is a good indicator for determining compost maturity.

#### *Ammonium and nitrate nitrogen concentration*

The general high  $\text{NH}_4^+$  -N contents in the compost samples from the initial days of composting till 78 days and the subsequent decrease for the rest of the composting process (Figure 4.9) probably might be due to volatilisation, immobilisation by microorganisms during decomposition of organic matter ,and nitrification. Meanwhile values of  $\text{NO}_3^-$  -N (Figure 4.10) increased during composting. This trend is typical of a good composting process (Raffaldi et al.,1986). The decreasing  $\text{NH}_4^+$  -N concentration to lower levels has been used in determining the quality of the mature product and process performance (Finstein and Miller,1985; Sesay et al.,1997). In a well managed composting process, much of the readily available N is converted into stable forms that resist further ammonification (Miller,1992). The drop in  $\text{NH}_4^+$  -N concentration to low level (0.06%-0.1% ) therefore indicates favourable composting conditions. According to Zucconi and de Bertoldi (1987), ammonium values above 0.04% are indicative of toxicity. With the exception of treatment CA which recorded an  $\text{NH}_4$  value of (0.06%) and corresponding GI at 60 % the other treatments recorded GI between 97% and 150% at 138 days although their ammonium levels were above 0.04%. From Table 4.8a it can be seen that satisfactory germination is obtained up to ammonium values of 0.1%. Therefore the ammonium values above 0.04% used to determine city compost

toxicity (Zucconi and de Bertoldi, 1987) may not apply in the case of oil palm- based residue compost.

The higher nitrate values recorded were expected because the decomposition undergone by the organic nitrogen during the composting brings about the production of ammonium and its subsequent oxidation to nitrate. This explains why the ammonium values increased gradually till a certain time before it started declining. This result therefore agrees with Finstein and Miller (1985) that compost is matured when appreciable quantities of nitrates appear after 123 days.

#### *Germination index*

Immature compost is one that has the organic matter not sufficiently stabilized as regards to its mineralization. It contains phytotoxic compounds such as ammonia which may cause toxicity to the roots and normal development of plants. Depending on the types of organic matter used time for maturity may vary.

Zucconi et al. (1981ab) and Tiquia et al. (1996 ) recommended a GI of 50% and between 80 to 85%, respectively, to indicate compost maturity. These differ from the results obtained in this experiment. Compost maturity occurred at a GI of 100% when the treatments were above 98 days old. This could be due to the different seeds used (Tomato seeds instead of *Lepidium*). The different maturing days of the treatments is also an indication that the compost materials have effect on maturity.

The early maturing of treatment CC might be due to the nature of the substrates. It contained mesocarp fibre which easily absorbs and maintains moisture for a longer time thereby creating conducive environment for the microorganisms to break down the organic matter and stabilise the end product. The absorbed moisture might have also prevented the EFB from drying up to assume crystalline state. Similarly, the early maturing of treatment CE might also be attributed to the presence of cocoa pod

husks and PKC. The cocoa pod husks and PKC might have served as a good substrate for the proliferation of microorganisms and hence increased microbial activity. The higher values of CI between the first 98 days and which lagged behind treatments CC and CE might be the result of the presence of the rock phosphate. The rock phosphate dissolved during the composting process which decreased the pH of treatment CI (Figure 4.8). And since the optimal pH for most organisms to function best is around 6.5 to 7.5, it is likely that the pH slowed the activities of the microorganisms. The increases in GI values corresponded with decreases in concentrations of  $\text{NH}_4^+\text{-N}$ .

### 5.3 EFFECT OF DIFFERENT ORGANIC WASTE MIXTURES ON CHEMICAL CHARACTERISTICS OF MATURED COMPOST

#### 5.3.1 pH

The final pH values obtained (6.0-7.9) for the compost were within the ranges of values reported by Sharma et al. (1997) Suhaimi and Ong (2001) Aisueni (2002). The significant differences in the pH of treatments CA and CC; CE and CL; CH and CK might be attributed to the effect of mesocarp fibre, cocoa husk, poultry waste and rock phosphate that were added to the mixture (Table 4.8b). Cocoa pod husk had a pH of 9.2, followed by poultry waste (8.5) and Mesocarp fibre (6.0). These might have raised the pH in addition to the effect of EFB in treatments CC, CE and CH. Conversely, rock phosphate might have decreased the pH of treatment CK. This is an indication that pH of the final compost depends on the types of composting materials used .

Measurement of pH of compost is useful for predicting effects on plant growth. The neutral pH attained might be due to degradation of carbohydrates into humic and fulvic acids (Spaggiari and Spigoni, 1986) together with ammonification of inorganic nitrogen at the end of the composting process (MacGregor et al., 1981; Thambirajah et al., 1995). Compost having such a range of pH (6.0-7.9) is of good agronomic value and will enhance successful crop production when applied to soil.

#### 5.3.2 Organic Matter

The addition of MF to treatment CC did not cause any significant increase in the organic matter content. Similarly, the cocoa pod husk in treatment CE and the

poultry waste in CH did not significantly increase their organic matter contents when compared to CL and CK, respectively. However, the significant difference between CA and CM; CG and CH might be attributed to the POME that was added. The untreated POME contains high concentration of non-pathogenic bacteria (Masheswaran, 1997) which might have caused the effective digestion of the composting materials. The different compost treatments contained high organic matter content (between 34.3% and 45.8%) which is above the 20% that was recommended for good quality municipal waste compost (van Os, 1996). The high organic matter content of the compost is due to the high organic matter contents of the composting materials (Table 4.4 and 4.7). The different composts can therefore be recommended as organic fertilizers for use in soils which are deficient in organic matter. Incorporation of such composts to the soil will serve as source and sink of nutrients, improve soil structure formation, detoxify harmful soil constituents and retain moisture (Golueke, 1981; Oades, 1984; Lavelle, 1988). The compost will buffer the nutrient availability to plants and reduce nutrients lost from the soil following disturbance at time of planting.

### **5.3.3 Nitrogen**

The increase in total nitrogen as composting progresses (Table 4.8b) confirm earlier reports of (Bernal et al.,1998b; Thambirajah et al.,1995;Sánchez –Monedero et al.,2001).This total N increase might be due to concentration effect caused by strong degradation of labile organic carbon compounds which reduces the weight of composting materials (Bernal et al.,1998b; Sánchez –Monedero et al., 2001) and loss of volatile solids which supersedes the loss of NH<sub>3</sub> (Bernal et al.,1998b; Meunchang et al., 2004).The nitrogen content of the composts (2.0%-4.5%) recorded confirms earlier values of 2.8 % and 3.3% reported by Suhaimi and Ong (2001) and Aisueni

(2002). The significant differences between treatments CA and CM, and CE and CL might be due to the POME and cocoa husks that were respectively present in CA and CE (Table 14). POME and cocoa pod husks contain high nitrogen content (1.8% and 1.47%, Table 4.4 and 4.7) which might have been released into the compost mixture during decomposition. Similar explanation can be cited for PKC and PW. Compost treatments that contain PKC and or PW recorded higher nitrogen values (Table 4.8b). Similarly, treatments that contained all or any one of these materials POME, PKC, PW and or cocoa husks did not show any significant differences. Example can be seen in treatments CH and CK, CE and CI, CI and CK. This implies that the addition of POME, PKC, PW or cocoa pod husks to composting materials have significant impact on the nitrogen levels of the final compost that is produced.

The compost quality in terms of nitrogen is very good. It is above the 0.3-1.6% that most authors have reported for Municipal compost (Obeng and Wright, 1987; IWMI, 2003).

#### **5.3.4 Ammonium and Nitrate Nitrogen**

The high ammonium and low nitrate recorded for treatments CD, and CM might be due to the water application rather than POME. Similarly, the low ammonium and high nitrate recorded by treatments CA, CC, CE and CI might be due to the POME, cocoa pod husks, and poultry waste that were incorporated into the mixtures. The water might contain low population of nitrifying bacteria (*Nitrosomonas* and *Nitrobacter*) to convert the ammonium to nitrate. But water treatments (CB and CG) which contained cocoa pod husks and poultry waste in addition recorded higher nitrogen values. The cocoa pod husks and the poultry waste might have added more nitrifying bacteria to the medium which effectively convert

ammonium to nitrate. Secondly, pH also influences the occurrence and activity of microorganisms. For example, *Nitrosomonas* and *Nitrobacter* prefer more neutral conditions (Johnston, 2004), and so the low pH of treatments CB,CD,CG and CM (6.0-6.4) might have affected their activities. The same reason explains the significant differences between CE and CL, CH and CK and CE and CI. Similarly POME might contain more nitrifying bacteria (Maheswaran, 1997) than water hence the significant difference in nitrate values reported between CA and CM and CG and CH. The addition of POME, cocoa pod husks, and poultry waste to composting materials to increase nitrate levels is therefore recommended.

### 5.3.5 Phosphorus

The high significant values of phosphorus concentration in treatments CI, CJ and CK were due to the addition of rock phosphate (Table 3.4). The same reason explains the significant difference among the following treatments: CI and CL, CJ and CA, CK and CE. The mixing of the organic materials and rock phosphate has been reported to cause temporary increase in soil microbial biomass (Ocio et al., 1991; He et al., 1996) which might have resulted in the removal of labile P, promoting PR dissolution in the compost. In addition, organic acids that are produced from the decomposition of organic materials might have also enhanced the dissolution of the applied PR in the compost (Mishra and Banger, 1986; Tander, 1987; Kpombekou-A and Tabatabai, 1994). A positive relationship between PR dissolution rate and soil organic matter content has been reported (Khasawneh and Doll, 1978).

Cocoa pod husks might account for the significant differences in P between treatment CI and CK. The higher P in treatments CG and CB might be as a result of the poultry waste that were applied since poultry waste contained high levels of P

(2.21%, Table 4.7). Similarly, the use of PKC in treatment CI might explain the significant difference between CI and CJ, CI and CK. Relatively, PKC contained high P (0.7%, Table 4.7) which might have been released during composting. On the other hand the insignificant difference in P between CK and CJ might be due to the dilution effect of cocoa pod husks in CK. This implies that the combined use of CH and RP in the same composting mixtures may not be important in increasing P content. However, it is advantageous to add either PR or PW and PKC to increase P level in compost.

### **5.3.6 Potassium**

Although the EFB might contribute significantly to the increase of K in the various compost treatments, the high values recorded by CE, CB, CG and CH might have come from the addition of the cocoa pod husk. Cocoa pod husks contain 3.4% potassium (Table 4.7), which might have been released during decomposition under pH below 7 (Rubaeka et al., 1998). The insignificant differences recorded among treatments CB and CE, CG and CH is an indication that neither POME nor water has effect on the release of K from cocoa pod husks. On the other hand the significant differences in P between CH and CK might be due to the contribution of poultry waste in CH. Thus cocoa pod husk and poultry waste can be used to significantly raise the level of potassium in compost.

### **5.3.7 Calcium and Magnesium**

All the treatments containing PR recorded high values for Ca and Mg (Table 4.8b). This might explain the insignificant differences recorded among treatments CI, CJ and CK. Rock phosphate contains high amount of Ca (50%) and this might have

increased the exchangeable Ca and Mg in the compost (Baligar, 2001). Conversely, treatments containing cocoa pod husks have recorded low values of Ca. There is also an inverse relationship between exchangeable Ca and Mg and potassium (Table 4.8b). Treatments CE, CB, CG and CH that were high in K showed low values in Ca and Mg and vice versa. This might be due to interaction. High K concentration first results in Mg deficiency and when K is in greater imbalance causes Ca deficiency (Jones et al., 1991). RP can therefore be used to increase Ca and Mg levels in compost in addition to phosphorus.

#### 5.4 EFFECT OF COMPOST ON GROWTH PARAMETERS AND NUTRIENT UPTAKE OF TWO DIFFERENT OIL PALM VARIETIES

##### **5.4.1 Effect of Compost Treatments on Mean Number of Leaves, Leaf Width and Length, Seedling Height and Bole Diameter of OPRI Oil Palm Seedlings**

In general, OPRI seedlings in compost treatments showed higher growth as compared to seedlings from NPK treatment (T<sub>11</sub>) or the Flanamite (T<sub>5</sub>) (Table 4.11a and b) (Plate 4.11). The higher mean number of leaves, seedling width, seedling height and bole diameter recorded by compost treatments T<sub>7</sub>, T<sub>4</sub>, T<sub>3</sub>, T<sub>6</sub> and T<sub>9</sub> might be due to higher nutrient and organic matter content contributed by the respective compost treatments (Table 4.8b). The organic matter might help in binding the soil fine particles together into aggregates (Oades, 1984) thereby making it loose for root development (Table 4.12). It also improves soil microbial activity and water storage at the root zone of the plants (Zougmore et al., 2004) and enhances nutrient uptake (Table 4.13). This might account for the significant differences between T<sub>7</sub> and T<sub>11</sub> or T<sub>5</sub>.

Similarly, the higher nitrogen, potassium and magnesium absorbed in T<sub>1</sub> (Table 4.15) might have accounted for the significant differences between T<sub>1</sub> and T<sub>10</sub>. POME which is rich in nutrients (both macro and micro nutrients) (Ngan et al., 1996) might have contributed significantly to the nutrient supply in T<sub>1</sub> seedlings as compared to T<sub>10</sub> which is water only. On the other hand, the lower mean number of leaves, leaf width, leaf length, seedling height and bole diameter observed in treatments T<sub>11</sub> might be due to soil structure effect as a result of low organic matter content (0.96%) (Table 3.5). Low soil organic matter easily gets destroyed on

watering by rainfall or irrigation water, thereby causing leaching of nutrients and impairment of plant development (Mafongoya et al., 2003).

#### **5.4.2 Effect of Compost Treatment on Mean Number of Leaves, Leaf Width and Length, Seedling Height and Bole Diameter of La Mé Oil Palm Seedlings**

Compost application increased the mean number of leaves, leaf width, leaf length and bole diameter of La Mé oil palm seedlings in treatments T<sub>3</sub>, T<sub>8</sub>, T<sub>9</sub>, T<sub>2</sub> and T<sub>1</sub>. This might be due to higher nutrient and organic matter content contributed by the treatments (Table 4.10 a and b). On the other hand, the lower mean number of leaves, leaf width, leaf length, seedling height and bole diameter observed in treatment T<sub>11</sub> might be attributed to soil structure effect as a result of low organic matter content (0.96%) (Table 3.5).

#### **5.4.3 Comparison of Growth Performance between OPRI and La Mé Oil Palm Seedlings**

The significant increase in mean number of leaves, leaf width, length, seedling height and bole diameter in La Mé seedlings over OPRI seedlings in corresponding compost treatments might be due to increased nutrient uptake. For example, La Mé seedlings responded vigorously to optimal nutrient supply as compared to OPRI seedlings (Table 4.13 and 4.14). When the soil medium was adequate in supplying nutrients, growth of La Mé seedlings were better than OPRI seedlings. However, when the nutrient supply was deficient, the growth of OPRI seedlings was better than La Mé. The over 36 and 55% nitrogen uptake by OPRI seedlings in T<sub>5</sub> and T<sub>11</sub> respectively as compared to La Mé seedlings confirmed this

(Table 4.15). This means that differences exist in the nutrient uptake profiles for the two oil palm seedlings. This could be due to genetic differences in the conversion of nutrients into dry matter.

#### 5.4.4 Root Volume of OPRI Oil Palm Seedlings

No significant difference in the root volume was observed between compost treatments and the NPK (T<sub>11</sub>) or the Flanamite (T<sub>5</sub>), Table 4.12. This might be due to the high P contents of T<sub>11</sub> (15%) and T<sub>5</sub> (4%) , since phosphorous specifically promotes root development (Hartley, 1988; Jacquemard, 1998). It might also be as a result of the ability of OPRI seedlings to thrive well in treatment T<sub>11</sub>, irrespective of the low organic matter content and its associated environmental stresses .

On the other hand the 3.74% and 1.33% increment in root volume of T<sub>6</sub> and T<sub>7</sub> over T<sub>8</sub> might be due to the effect of improvement in soil structure and enhanced P uptake. The poultry waste and PKC in the compost treatments might have succumbed more easily to wetting and drying which might have influenced the mineralization of P (Chepkwony et al., 2001) in treatment T<sub>6</sub> and T<sub>7</sub> (Table 4.4 and 4.7) as compared to T<sub>8</sub>. The mineralization increases P availability by (1) the formation of organophosphate complexes that are more easily assimilated by plants,(2) anion replacement of H<sub>2</sub>PO<sub>4</sub><sup>-</sup> on adsorption sites, and (3) the coating of Fe and Al particles by humus to form a protective cover and thus reduce P adsorption (Tisdale et al., 2002).

Organic anions produced from the decomposition of such poultry waste and PKC may also form stable complexes with Fe and Al, thus preventing their reaction with H<sub>2</sub>PO<sub>4</sub><sup>-</sup> . These complex ions also may release P previously fixed by Fe and Al by the same mechanism. The weakly acidic conditions of treatments T<sub>6</sub> and T<sub>7</sub> (5.96 and 6.15, Table 3.5), might have also affected P availability and uptake. Total

phosphorus uptake by T<sub>6</sub> seedlings was 133.18mg/plant, T<sub>7</sub> was 170.56 mg/plant whilst T<sub>8</sub> was 83 mg/plant (Table 4.13). This agrees with Johnston (2004) report that phosphorus uptake is faster under weakly acid conditions. Similarly, the over 21% and 20.32 % increment of root volume of T<sub>1</sub> and T<sub>4</sub> over T<sub>10</sub> and T<sub>9</sub> is an indication that POME and cocoa pod husk also contributed to the P level in soil and its uptake.

#### **5.4.5 Root Volume of La Mé Oil Palm Seedlings**

The significant differences observed in root volume between La Mé oil palm seedlings in compost treatments and NPK (T<sub>11</sub>) or T<sub>5</sub> might be attributed to the different nutrient levels as a result of the treatments. The La Mé seedlings unlike OPRI seedlings performed better in compost treatments that supplied enough nutrients to the plants. The low organic matter content and poor soil structure of treatment T<sub>11</sub> might have inhibited root development, caused increased mechanical resistance to root penetration and reduced efficiency of rapid nutrient uptake .

#### **5.4.6 Comparison of Fresh Root Volume of OPRI and La Mé Oil Palm Seedlings**

No significant difference in the root volume of OPRI and La Mé seedlings in compost treatments was observed. The compost treatments contained high organic matter (Table 3.5) which makes the soil loose for easy root development as well as providing enough nutrients for growth (Table 4.12). It also improve water storage at the root zone of the plants (Zougmore et al., 2004) which help the roots to grow (Tisdale et al., 2002).

On the other hand, the significant differences showed by OPRI over La Mé seedlings in the NPK (T<sub>11</sub>) and Flanamite (T<sub>5</sub>) might be attributed to varietal

differences. The OPRI seedlings was able to thrive well on adverse conditions as compared to La Mé seedlings (personal observation).

#### **5.4.7 Effect of Compost on Nutrient Uptake and Dry Matter Yield of Two Different Varieties of Oil Palm Seedlings (OPRI and *La Mé*)**

##### ***(i)OPRI oil palm seedlings***

###### *Total Nitrogen uptake*

The high nitrogen uptake by OPRI seedlings from compost treatments T<sub>7</sub>, T<sub>6</sub>, T<sub>2</sub>, T<sub>3</sub>, T<sub>8</sub> and T<sub>4</sub> might be attributed to the effect of organic matter and high nutrient supplied by the decomposition and mineralization of PW, POME or cocoa pod husks in the compost treatments. Organic matter holds nutrients and moisture which buffer extreme changes in soil temperature thereby enhancing nitrate uptake (Millar, 1965). The difference in nitrogen uptake between T<sub>1</sub> and T<sub>10</sub>, T<sub>7</sub> and T<sub>6</sub> implies that the POME which is rich in nutrients might have contributed significantly to nitrogen supply in T<sub>1</sub> seedlings as compared to T<sub>10</sub>. Similarly, the difference in T<sub>4</sub> and T<sub>9</sub> implies that the cocoa pod husks also contributed significantly to nitrogen supply.

###### *Phosphorus uptake*

The high phosphorus uptake in compost treatments T<sub>7</sub>, T<sub>6</sub> and T<sub>4</sub> might be due to media effect. Treatments T<sub>7</sub> and T<sub>6</sub> contained poultry droppings which have higher P content of 2.21%. Similarly, treatment T<sub>4</sub> contained PKC which has a P content of 0.7% (Table 4.4 and 4.7) . The poultry droppings and PKC might have mineralized easily for plant uptake. Secondly, the weakly acidic condition of treatments T<sub>7</sub>, T<sub>6</sub> and T<sub>4</sub> (6.4-6.8) might have increased P mineralization from the substrates and availability to the seedlings (Tisdale et al., 2002). The same pH effect

might explain the high uptake of P by OPRI seedlings from treatment T<sub>7</sub> over T<sub>8</sub> (Table 3.5). High amount of P is reported to be adsorbed into the soil at pH between 4 and 5 (Tisdale et al., 2002), and so the low pH of T<sub>8</sub> (4.86) might have caused more P to be adsorbed thereby preventing it from plants uptake.

Similarly, the high organic matter content of the compost treatments might also explain the high P uptakes as compared to NPK (T<sub>11</sub>). The organic compounds in the compost treatments increased P availability possibly by (1) the formation of organophosphate complexes that are more easily assimilated by plants, (2) anion replacement of H<sub>2</sub>PO<sub>4</sub><sup>-</sup> on adsorption sites, and (3) the coating of Fe and Al particles by humus to form a protective cover and thus reduce P adsorption (Eric et al., 2002; Tisdale et al., 2002).

The leaf P content of oil palm seedlings from the compost treatments were between 0.25% and 0.45% (Appendix 2) which is far above the P critical value for oil palm leaf (0.15%) (Prevot and Ollangner, 1954). The highest root volume (39.33ml/plant to 44ml/plant) recorded by seedlings from treatments T<sub>7</sub>, T<sub>6</sub> and T<sub>4</sub> might have been promoted by the higher P uptake (Table 4.13). This is an indication that compost from recycled agricultural and agro-industrial residues such as palm residues, cocoa pod husks and poultry wastes or RP could be used successfully to supply optimum P for oil palm growth and development.

#### *Potassium uptake*

The significant amount of K uptake by OPRI oil palm seedlings in treatments T<sub>7</sub>, T<sub>4</sub> and T<sub>6</sub> (Table, 4.13) as compared to T<sub>11</sub> and T<sub>5</sub> might also be due to the composition of the media. Treatments T<sub>7</sub>, T<sub>4</sub> and T<sub>6</sub> contained cocoa pod husk which is rich in K (3.35%) in addition to EFB (2.10%K). These might have mineralized and made more K available for plant uptake. The leaf K content of the treatments were

between 1.57% and 2.27% (Appendix 2) which is far above the K critical value for oil palm leaf (1.0% or less) (Prevot and Ollangner, 1954). The high uptake of P and K (Table 4.13) from the compost treatments confirms Motavilli (1993) reports that compost application increases plant uptake of phosphorus and potassium.

#### *Calcium and magnesium uptake*

The reasons given above also explain why there is high calcium and magnesium uptake in compost treated seedlings.

#### *Total dry matter yield*

No significant difference was observed in the total dry matter yield of OPRI seedlings for the compost treatments. This suggests that the mineralization rate among the compost treatments was enough to supply the amount needed for growth irrespective of the differences in their nutrient contents.

There was positive correlation between dry matter yield (DMY) and nutrient uptake ( $r = 0.9$ ). The coefficient of determination ( $R^2$ ) which gives the percentage of variation in the DMY explained by nutrient uptake gave ( $R^2$ ) value to be equal to 0.815. This implies that 82% of the variation in DMY can be explained by its association with nutrient uptake (N, P, K, Ca and Mg) and the remaining 18% could be due to other factors. Below is the regression equation for the DMY and nutrients uptake:

$$Y^n = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + B_5X_5 + \dots B_nX_n$$

$$DMY = 5.72 + 1.03 \times 10^{-2} N - 1.18 \times 10^{-2} P + 1.75 \times 10^{-2} K + 7.0 \times 10^{-2} Ca + 2.34 \times 10^{-2} Mg$$

#### *Relationship between root volume of OPRI seedlings and nutrient uptake*

Similarly positive correlation was observed between root volume (RV) and nutrient uptake (0.8). The change in root volume as a result of a unit increase in N uptake was  $3.25 \times 10^{-2}$ , P was  $7.53 \times 10^{-2}$  and that of K was  $3.23 \times 10^{-2}$ . This confirms earlier reports that phosphorus specifically promotes root development (Hartley, 1988 and Jacquemard, 1998). Regressing root volume versus nutrient uptake gave coefficient ( $R^2$ ) value of 0.648. This implies that 65 % of variations in root development is explained by nutrient uptake (K, P, N, Mg and Ca). Below is the regression equation for RV and nutrients uptake:

$$RV = 8.41 + 3.25 \times 10^{-2} N + (-7.53 \times 10^{-2}) P + 3.23 \times 10^{-2} K + (-0.28 \times 10^{-2}) Ca + 3.74 \times 10^{-2} Mg$$

### ***(ii) La Mé oil palm seedlings***

#### *Total Nitrogen uptake*

As noted earlier for OPRI the significant differences in nitrogen uptake in La Mé seedlings from compost treatments might be due to the effect of organic matter and high nutrients supplied by the compost treatments. The high pH of the compost treatments (6.0-7.9), high moisture content (Zougmore et al., 2004) among other factors might have created a favourable condition for La Mé seedlings growth and development. Such conditions also make nitrogen available as well as influencing its uptake (Johnston, 2004). Conversely, the low pH of the inorganic treatment (pH, 4.2), low organic matter content; low moisture content and variations in soil solution temperature might have affected the growth, development and nutrient demand of the La Mé seedlings.

### *Phosphorus uptake*

The PKC and the rock phosphate in compost treatment T<sub>3</sub>, T<sub>8</sub>, and T<sub>9</sub> together with the effects of organic compounds might have increased the P availability and supply to La Mé seedlings in compost treatments over the NPK, T<sub>11</sub> or T<sub>5</sub>.

### *Potassium uptake*

Similarly, the significant differences in K uptake among compost treatments over T<sub>11</sub> and T<sub>5</sub> (Table 4.14) might have been contributed by the empty fruit bunches in the compost treatments (Table 4.4).

### *Calcium and magnesium uptake*

The reasons given above also explain why there is high calcium and magnesium uptake in compost treated seedlings.

### *Total dry matter yield*

The significant growth observed in La Mé seedlings in compost treatments over T<sub>11</sub> and T<sub>5</sub> might be due to rapid growth as a result of improvement in soil structure moisture content and nutrient uptake. Dry matter yield of La Mé seedlings showed very strong positive correlation to nutrient uptake ( $r = 0.96$ ). The change in DMY as a result of a unit increase in nitrogen uptake was  $5.64 \times 10^{-2}$ , P uptake was  $9.67 \times 10^{-2}$  and that of K was  $2.71 \times 10^{-2}$ . Regressing DMY of La Mé seedlings against nutrient uptake gave a coefficient ( $R^2$ ) value of 0.929. This implies that 93 % of variations in DMY is explained by nutrient uptake with the rest being due to other factors. Below is the regression equation for the DMY of La Mé seedlings and nutrients uptake:

$$\text{DMY} = 2.24 + 5.64 \times 10^{-2} \text{N} + 9.67 \times 10^{-2} \text{P} + 2.71 \times 10^{-2} \text{K} + 0.24 \times 10^{-2} \text{Ca} + (-0.12 \times 10^{-2}) \text{Mg}$$

*Relationship between root volume of La Mé seedlings and nutrient uptake*

Like OPRI seedlings there is a very strong positive correlation between root volume and nutrient uptake ( $r = 0.77$ ). The change in RV as a result of unit increase in N uptake was  $6.55 \times 10^{-2}$ , P was  $7.5 \times 10^{-2}$  and that of K was  $3.23 \times 10^{-2}$ . Regressing root volume versus nutrient uptake gave coefficient ( $R^2$ ) value of 0.588. This implies that 55 % of variations in root volume is explained by nutrient uptake (K, P, N, Mg and Ca). The regression equation for the root volume and nutrients uptake is shown below:

$$RV = -8.364 + (-6.55 \times 10^{-2}) N + 7.5 \times 10^{-2} P + 3.23 \times 10^{-2} K + 1.17 \times 10^{-2} Ca + (-7.04 \times 10^{-2}) Mg$$

**5.4.8 Comparison of Nutrient Uptake between OPRI and La Mé Oil Palm Seedlings**

The significant differences in the uptake of N,P,K, Ca and Mg between La Mé seedlings and OPRI oil palm seedlings might be attributed to the difference in their genetic make-up and other growth promoting resources such as water, effective sunshine, and temperature (von- Uexkull, 2004). The significant differences in the dry matter yield of La Mé seedlings over OPRI seedlings in compost media implies that La Mé seedlings responded more to the conditions that were prevailing in the compost treatments. On the other hand the high nutrient uptake by OPRI seedlings in the NPK T<sub>11</sub> and Flanamite (T<sub>5</sub>) is an indication that the compost could not readily supply sufficient amount of nutrient required by OPRI seedlings for rapid growth. It is therefore advisable for a further study to be carried out into the nutrient release pattern of the different compost products.

## 5.5 SOCIETAL PERCEPTION AND OPINION ON COMPOSTING AND THE USE OF COMPOST FOR AGRICULTURAL PURPOSES

The success of composting partly depends on societal perception and willingness to buy and use the compost (i.e. the market demand). The high interest and willingness of the palm oil Mill managers (96%) to recycle the residues and the public preparedness to buy and use compost for agricultural purposes (92%) is an indication that composting is a potential sustainable method to managing palm residues. This also agrees with earlier reports that compost may be suitably used as an organic fertilizer where cheaper poultry manure is not accessible (Danso et al., 2002; Eriksen-Hamel, 2002). On the other hand the fact that 90% of the managers reported not to have any knowledge in composting, and the high interest shown by potential compost users to be trained in composting imply that the composting process needs to be looked at in order to recommend a guideline for successful composting. Meanwhile, the doubt raised by some of the respondents on the efficiency of the compost calls for a further study into the effect of the compost products on oil palm seedlings (the major cash crop grown in the study area).

## CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

### 6.1 CONCLUSION

Twenty-two oil processing mills were identified in the Kwaebibirem district. These included twenty small scale Mills, and one each of a highly automated medium, and a large scale Mill. The mills had common units of operation (Figure 4.1 and 4.2) hence generated common residues (mostly EFB, MF and POME). However, the high capacity of the large scale Mill (48 tons/hr) with an extraction rate of about 20% of oil, in addition to a palm kernel crushing plant of 45 tons/day caused the large scale Mill to generate PKC, EFB and POME more than all the 20 small scale Mills put together. Whereas the large scale Mill treated the POME through anaerobic digestion, the small scale Mills did not, but rather poured the untreated POME into the environment. The washing of the POME during and after rainfalls together with the poor management of EFB and MF were found to impact negatively on the water bodies near the oil palm processing mills.

The study further discussed the environmental threat associated with the Presidential Special Initiative (PSI) on oil palm if the oil palm residues are not treated properly. To prevent such future threat, possible waste management methods were discussed. Since the anaerobic digestion method being used by the large scale Mill is expensive and requires skills and management commitments beyond the capacity of the small scale processing Mills, composting was proposed as the best alternative treatment option because of its cost effectiveness, environmental friendliness and flexibility.

A study into the composting process of the residues revealed that the compost treatments matured at different periods. Despite these differences, 138 days could be used as a mean maturity time for composting. The differences were the result of the

different residue mixtures contained in the treatments. Treatment CC (EFB+MF+POME) matured earlier whilst CA (EFB +POME) matured late. The late maturing of treatment CA was attributed to the fibrous nature of the EFB which makes it more crystalline when dried and more difficult to decompose.

The biochemical characteristics of the different composts studied showed that an alkaline pH (6.4-7.9) for more than 24 hours, CO<sub>2</sub> evolution (less than 2.0 mg g<sup>-1</sup>d<sup>-1</sup>), constant temperature of 30°C and appreciable amounts of nitrate were found to correlate best with tomato seed germination test in determining the maturity of compost from agricultural and agro-industrial residues.

The mixture of POME, PKC, cocoa pod husks, poultry waste or Phosphate Rock as a composted material significantly improved the nutrient content of the compost treatments. Nitrogen (N) content ranged between 2% in T<sub>10</sub> to about 5% in T<sub>3</sub>, highest phosphorus (P) was recorded in T<sub>8</sub> (4.4%) and highest potassium (K) in T<sub>4</sub> (3.97%). The organic matter content of the resulting composts was very high (between 25-45.78% C). This was attributed to the high organic matter contents of the composting materials. The composting materials also affected compost quality (i.e. nutrients and pH). For example, poultry wastes, POME and cocoa pod husks increased total nitrogen contents of the compost treatments while Rock Phosphate and poultry waste increased P content. Similarly, cocoa pod husks and EFB increased K contents.

Oil palm seedlings (OPRI and La Mé) grown in the compost treatments recorded higher number of leaves, leaf width, leaf length, seedling height, bole diameter, root volume and total dry matter yield than seedlings from the NPK (T<sub>11</sub>) or imported organic fertilizer (T<sub>5</sub>, Flanamite). Fresh root volume of La Mé seedlings in compost treatments was significantly higher than the NPK (T<sub>11</sub>) and Flanamite (T<sub>5</sub>). Higher DMY was observed on compost treatments for both OPRI and La Mé

seedlings as compared to NPK (T<sub>11</sub>). The two different oil palm varieties responded differently to the different compost treatments. OPRI seedlings performed well in treatments T<sub>7</sub>, T<sub>3</sub>, T<sub>6</sub>, T<sub>4</sub>, T<sub>9</sub> and T<sub>8</sub> whilst La Mé seedlings did well in treatments T<sub>3</sub>, T<sub>8</sub>, T<sub>9</sub>, T<sub>2</sub> and T<sub>1</sub>.

Uptake of N, P, K, Ca and Mg by La Mé seedlings from compost treatments was significantly higher than the uptake in the NPK and Flanamite treatments. Among the compost treatments no significant differences were observed in the nutrient uptake by either OPRI or La Mé seedlings. Meanwhile over 36-55% more nitrogen uptake was observed in OPRI seedlings over La Mé seedlings from treatments, T<sub>11</sub> and T<sub>5</sub>. This suggests that the OPRI seedlings absorbed more nitrogen than La Mé seedlings in these treatments.

The correlation between the DMY of OPRI seedlings and nutrient uptake is ( $r = 0.90$ ), and that of La Mé is ( $r = 0.96$ ). About 82% of the variation in DMY of OPRI seedlings was explained by its association with nutrient uptake (N, P, K, Ca and Mg) whilst 93 % variation in the DMY of La Mé seedlings is also explained by nutrient uptake.

Surveys conducted with questionnaires and interviews on the perception and willingness of the managers of the Mills and potential compost users (200 respondents) revealed that 92 to 96% of the respondents perceived compost as good and were ready to compost and use the compost for agricultural purposes. It is recommended therefore that composting could be considered as an effective method of managing agricultural and agro-industrial waste and in particular for the oil palm industry, it should be given utmost priority.

## 6.2 RECOMMENDATIONS

The discharge of untreated POME into the environment by the small scale processing mills is not a good practice and must be stopped immediately. It is recommended that the abundance of the residues can be totally recycled by the oil palm processing Mills and so a composting unit could be created in addition to the oil palm processing unit. Where the oil palm processing Mills are not able to recycle all the waste, other private individuals can take advantage of that as a source of income generation. There is potential market to use the compost from these residues for oil palm nursery establishment, vegetable cultivation and as potting medium for horticultural crops.

For successful growth of oil palm seedlings at the pre-nursery and nursery stages, the following composting mixtures are recommended in priority order shown T<sub>7</sub>(EFB+PKC+CH+PW+POME); T<sub>4</sub>(EFB+PKC+CH +POME) and T<sub>6</sub> ( EFB+PKC +CH+PW+WATER). To assure compost maturity, the following indices should be used: an alkaline pH (6.4-7.9) medium for more than 24 hours, CO<sub>2</sub> evolution (less than 2.0 mgg<sup>-1</sup>d<sup>-1</sup>), constant temperature of around 30°C, appreciable amount of nitrates and high seed germination test > 100%. However, a further study is needed to reduce the composting period from 138 days through the use of e.g., vermicultures.

For pre-nursery establishment of oil palm seedlings (both OPRI and La Mé) one part of compost to two parts of subsoil is appropriate. Thereafter, application of 15g compost per seedling per month from the fourth months till the end of 12 months can sustain the successful growth of oil palm seedlings at the nursery.

A study into the long term effect of compost on plant yield is also recommended.

In addition the Environmental Protection Agency (EPA) needs to improve its monitoring activities and ensure good quality of water bodies near palm oil producing areas.

Furthermore, composting should be looked at as one of the major priorities by the government under the PSI programme on oil palm. The strategic plan for the palm oil cultivation under the PSI should make provision for research, education and training in recycling through composting and to support individuals and private companies that may want to go into composting of oil palm residues as well as commercial enterprise.

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## APPENDIX 1: QUESTIONNAIRES

**Questionnaire on perception of oil processing industries to recycle oil palm residues****INTRODUCTION**

As part of the partial fulfilment of the requirement for the degree of M. Phil. Environmental Science, students of the University of Ghana are required to solve social and environmental issues relating to their research work. It is in view of this that the following questionnaire is prepared to help identify the problems associated with the management of oil palm residues, their uses and impact on the environment. Your co-operation is therefore highly needed.

**Name of industry**-----

**Location of industry**-----

**Name of the technical director or manager of the mills**-----

-----**Total number of workers in the industry** -----

**No of male workers in the industry** -----

**No of female workers in the industry**-----

(1) How long has the industry been in operation-----

(2) What quantity of fresh oil palm fruit is processed weekly?

(3) What quantity of palm oil is sold in a week? -----

(4) What types of waste do you generate in your company? -----

-----

(5) What problem does the waste pose to you?-----

(6) How do you treat or manage the waste? -----

(7) Do you encounter any problem when treating the waste? **Yes or No**

(8) Have you heard of composting? **Yes or No**

(9) If **Yes** do you have any technical know how in composting? **Yes or No**

(10) Would you be prepared to compost the palm wastes? **Yes or No**

(11) Would you like to be trained in composting? **Yes or No**

(12) If **No** give reason(s)? -----

-----

(13) If **yes** what would you like to use the compost for? -----

(14) If potential users of compost express interest in buying it, would you be prepared to go into composting as additional business to your already existing services? **Yes or No**

(16) If **No** why wouldn't you go into composting as another business?-----

(17) If **yes** what assistant would you like to receive in order to go into composting as a business?---

-----

**Thank you for your co-operation and contributions.**

**Questionnaire to ascertain the willingness of potential compost users to use compost in agriculture**

**INTRODUCTION**

As part of the partial fulfilment of the requirement for the degree of M. Phil. Environmental Science, students of the University of Ghana are required to solve social and environmental issues relating to their research work. It is in view of this that the following questionnaire is prepared to help identify problems relating to composting of wastes, uses and acquisition of compost, and to recommend the best solutions to the identified problems. Your co-operation is therefore highly needed.

**Name** ----- **Age** ----- **Sex:** -----

**Occupation** -----

**Marital status** ----- **No. of children**-----

**Religion** ----- **Tribe** -----

**Name & address of company, if any** -----

----- (1) How long have you been in this occupation? (a) 1-5 yrs (b) 6-10 yrs (c) 11-20 yrs  
(d) 21yrs and above

(2) Do you add anything to improve the fertility status of your soil? **Yes or No**

(3) If **Yes** what have you been adding?-----

----- (4) Why do you choose the product mentioned in 3 above? -----

(5) Have you heard about fertilizers? **Yes or No**

(6) If **Yes** mention the fertilizer(s) that you know -----

----- (7) Have you applied any of the above-mentioned fertilizers before **Yes or No**

(8) If **No** then go to question 10

(9) If **Yes** what types of fertilizer have you applied?

(a) inorganic fertilizer (e.g. NPK, ammonium, urea etc)

(b) organic fertilizers only (e.g. compost, and manure).

(c) both organic and inorganic fertilizers

(d) state if it is not in the above.

(10) When was the last time you applied it .....

(11) Why don't you apply it? -----

(12) For those using organic fertilizer only or both organic and inorganic fertilizers, what type of organic fertilizers have you been using? (a)----- (b)----- (c)-----

(12) Have you ever heard of compost? **Yes or No**

(13) If **Yes** have you applied it before? **Yes or No**

If **No** go to question (27).

(14) When was the last time you applied compost-----

(15) Where did you acquire it? -----

(16) Do you face any problem in its acquisition? **Yes or No**

(17) If **Yes** what are the problems?-----

(18) If compost is acquired from a distant source have you encountered any problems in its transportation? **Yes or No**

(19) If **Yes** then mention the problem(s)-----

(20) If compost is bought, how much does it cost per tonne or Tipper Truck? -----

(21) If compost is transported from a distant place, how much does it cost per tonne or Tipper Truck? -----

(22) What do you use compost for?

- (a) for landscaping
- (b) for growing flowers
- (c) for growing crops (e.g. vegetables)
- (d) other uses such as -----

(23) Do you notice any change after using compost? **Yes or No**

(24) If **Yes** what kinds of change do you notice? State your observations-----  
-----  
-----

(25) Did you come across any particular problem when using compost? **Yes or No**

(26) If **Yes** can you please mention them-----  
-----  
-----

(27) Why didn't you use compost?

- (I) Because of lack of training and technical advice
- (II) Because of cultural reasons( e.g. it is defiling to touch waste)
- (III) Because of the risk involved.
- (IV)Because of lack of institutional support
- (V) Because it is time consuming.

(a) I only (b) II only (c) I and II only (d) I,III and V (e) I and V only.

(28) How do you think the above- mentioned problems can be solved?  
-----  
-----

(29) Are you prepared to use compost if the reasons given above is or are solved?

**Yes or No**

(30) Which of these would you like?

- (i) to receive education on the importance and use of compost
- (II) to receive training in composting
- (III) to buy matured compost from manufacturing sources

(a) I only (b) II only (c) III only (d) I and II only (e) I, II and III

Thank you for yours co-operation and contributions.

## APPENDIX 2: NUTRIENT CONTENT OF PLANT PARTS

Table I: Effect of Compost on the Dry Matter Yield and Mean Nutrient Content of the Different Parts of OPRI Oil Palm Seedling at 7 Months

Treatment	Plant part	DMY	N	P	K	Ca	Mg
		g/plant	%	%	%	%	%
CA+SS(T <sub>1</sub> )	leaves	12.55	3.47	0.34	1.83	0.19	0.43
	Bole + petiole	6.91	2.13	0.40	1.67	0.11	0.47
	Roots	5.02	2.47	0.33	2.90	0.00	0.18
CC+SS(T <sub>2</sub> )	leaves	12.78	4.13	0.42	2.03	0.21	0.37
	Bole + petiole	10.47	3.41	0.39	2.08	0.16	0.36
	Roots	5.67	2.07	0.35	1.51	0.00	0.18
CD +SS(T <sub>3</sub> )	leaves	12.40	3.60	0.30	1.60	0.26	0.32
	Bole + petiole	6.83	3.53	0.44	1.61	0.15	0.34
	Roots	4.98	2.87	0.35	1.87	0.01	0.24
CE+SS (T <sub>4</sub> )	leaves	13.47	2.93	0.38	2.13	0.28	0.48
	Bole + petiole	8.46	2.93	0.38	1.39	0.12	0.31
	Roots	6.63	2.27	0.42	2.93	0.00	0.22
F+SS (T <sub>5</sub> )	leaves	10.50	3.60	0.36	1.87	0.26	0.57
	Bole + petiole	6.69	2.93	0.33	1.70	0.16	0.59
	Roots	4.73	2.27	0.30	2.67	0.01	0.28
CG+SS(T <sub>6</sub> )	leaves	14.06	3.73	0.45	1.57	0.16	0.50
	Bole + petiole	8.09	2.93	0.60	2.07	0.09	0.58
	Roots	5.98	2.53	0.38	2.97	0.00	0.21
CH +SS (T <sub>7</sub> )	leaves	17.27	2.93	0.25	2.27	0.18	0.41
	Bole + petiole	9.88	3.20	1.07	1.50	0.07	0.43
	Roots	6.23	2.27	0.34	2.50	0.03	0.26
CI+SS (T <sub>8</sub> )	leaves	6.12	2.23	0.36	1.64	0.06	0.30
	Bole + petiole	7.10	2.67	0.42	1.87	0.11	0.47
	Roots	5.14	2.93	0.40	2.47	0.00	0.21
CL+SS (T <sub>9</sub> )	leaves	12.94	3.40	0.41	1.47	0.25	0.51
	Bole + petiole	7.71	2.53	0.44	1.40	0.11	0.43
	Roots	4.02	1.87	0.32	1.74	0.00	0.22
CM +SS(T <sub>10</sub> )	leaves	11.64	3.20	0.28	1.57	0.22	0.31
	Bole + petiole	6.95	1.87	0.34	1.57	0.06	0.29
	Roots	4.81	1.73	0.30	1.87	0.01	0.19
CO +SS(T <sub>11</sub> )	leaves	11.60	3.80	0.30	1.37	0.24	0.33
	Bole + petiole	7.09	2.67	0.31	0.92	0.07	0.34
	Roots	4.63	2.80	0.28	2.30	0.00	0.23

Table II: Effect of Compost on the Dry Matter Yield and Mean Nutrient Content of La Mé Oil Palm Seedling at 7 Months

Treatment	Plant Part	Plant DMY g/plant	N %	P %	K %	Ca %	Mg %
CA +SS(T <sub>1</sub> )	leaves	15.13	3.67	0.35	2.30	0.14	0.31
	bole + petiole	10.98	2.27	0.51	2.50	0.09	0.51
	Roots	5.97	1.80	0.43	2.03	0.01	0.19
CC+SS (T <sub>2</sub> )	leaves	17.16	3.33	0.49	1.70	0.35	0.46
	Bole +petiole	14.75	1.40	0.40	0.57	0.14	0.32
	Roots	5.78	2.53	0.41	1.87	0.00	0.22
CD +SS(T <sub>3</sub> )	leaves	17.16	2.80	0.30	1.27	0.20	0.31
	Bole +petiole	12.08	1.87	0.54	1.23	0.06	0.36
	Roots	6.08	1.87	0.54	2.13	0.01	0.21
F+SS (T <sub>5</sub> )	leaves	4.85	3.87	0.35	1.77	0.32	0.35
	Bole +petiole	3.35	2.27	0.36	1.15	0.12	0.38
	Roots	1.65	2.40	0.42	2.00	0.01	0.22
CI +SS (T <sub>8</sub> )	leaves	17.82	2.73	0.40	2.23	0.40	0.66
	Bole +petiole	13.40	1.47	0.38	0.93	0.15	0.41
	Roots	6.43	1.33	0.32	2.00	0.00	0.17
CL+SS(T <sub>9</sub> )	leaves	16.34	2.80	0.37	1.50	0.34	0.47
	Bole +petiole	11.23	2.00	0.38	0.90	0.15	0.41
	Roots	4.50	1.60	0.33	2.40	0.02	0.19
CO +SS(T <sub>11</sub> )	leaves	6.43	2.07	0.23	1.10	0.37	0.42
	Bole +petiole	4.49	1.47	0.27	0.91	0.08	0.34
	Roots	1.66	1.60	0.24	2.07	0.01	0.19

## APPENDIX 3: ANOVA TABLES

Table III

**ANOVA showing the effect of different organic mixtures on chemical characteristics of compost at maturity**

Variate:pH

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Reps stratum	2	0.06500	0.03250	2.13	
Treatment	11	10.78750	0.98068	64.40	<0.001
Residual error	22	0.33500	0.01523		
Total	35	11.18750			

Variate:%C

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Reps stratum	2	1.355	0.677	0.63	
Treatment	11	986.634	89.694	83.76	<.001
Residual error	22	23.560	1.071		
Total	35	1011.549			

Variate:%N

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Reps stratum	2	0.0431	0.0216	0.11	
Treatment	11	16.2950	1.4814	7.45	<.001
Residual error	22	4.3773	0.1990		
Total	35	20.7154			

Variate:%NH<sub>4</sub>-N

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Reps stratum	2	0.0013500	0.0006750	1.00	
Treatment	11	0.6572000	0.0597455	88.51	<.001
Residual error	22	0.0148500	0.0006750		
Total	35	0.6734000			

Variate:%NO<sub>3</sub>-N

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Reps stratum	2	0.0003500	0.0001750	0.75	
Treatment	11	0.4729417	0.0429947	175	<.001
Residual error	22	0.0053833	0.0002117		
Total	35	0.4786750			

Variate:% P

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Reps stratum	2	0.06889	0.03444	2.69	
Treatment	11	71.67983	6.51635	508.65	<.001
Residual error	22	0.28184	0.01281		
Total	35	72.03056			

Variate:%K

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Reps stratum	2	0.1878	0.0939	0.75	
Treatment	11	34.3032	3.1185	25.07	<.001
Residual error	22	2.7364	0.1244		
Total	35	37.2273			

Variate:%Ca

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Reps stratum	2	0.00005000	0.00002500	0.51	
Treatment	11	0.03694167	0.00335833	68.20	<.001
Residual error	22	0.00108333	0.00004924		
Total	35	0.03807500			

Variate: % Mg

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	0.000167	0.000083	0.06	
Treatment	11	0.0854083	0.0077644	59.94	<.001
Residual error	22	0.0028500	0.0001295		
Total	35	0.0882750			

ANOVA showing the effect of compost on growth of OPRI oil palm seedlings

ANOVA showing mean number of leaves of OPRI seedlings

Variate: Number of leaf

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	0.6816	0.3408	1.41	
Treatment	10	21.3391	2.1339	8.82	<1.41
Month	3	149.0442	49.6814	205.28	<.001
Treatment. Month	30	4.0641	0.1355	0.56	0.963
Residual error	86	20.8133	0.2420		
Total	131	195.9423			

ANOVA showing mean leaf width of OPRI seedlings

Variate: Leaf width

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	3.917	1.959	1.62	
Treatment	10	64.251	6.425	5.32	<.001
Month	3	1051.138	350.379	290.06	<.001
Treatment. Month	30	39.042	1.301	1.08	0.383
Residual error	86	103.885	1.208		
Total	131	1262.233			

ANOVA showing mean leaf length of OPRI seedlings

Variate: Leaf length

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	39.890	19.945	3.46	
Treatment	10	199.731	19.973	3.47	<.001
Month	3	3461.432	1153.811	200.39	<.001
Treatment. Month	30	92.203	3.073	0.53	0.973
Residual error	86	495.175	5.758		
Total	131	4288.431			

ANOVA showing mean seedling height of OPRI seedlings

Variate: Seedling height

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	124.760	62.380	6.78	
Treatment	10	658.295	65.830	7.15	<.001
Month	3	6939.118	2313.039	251.37	<.001
Treatment. Month	30	208.774	6.959	0.76	0.804
Residual error	86	791.355	9.202		
Total	131	8722.303			

ANOVA showing mean bole diameter of OPRI seedlings

Variate: Bole diameter

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	24.044	12.022	4.13	
Treatment	10	334.996	33.500	11.51	<.001
Month	3	4127.008	1375.669	472.55	<.001
Treatment. Month	30	65.330	2.178	0.75	<0.814
Residual error	86	250.363	2.911		
Total	131	4801.740			

**ANOVA showing the effect of compost on growth of La Mé oil palm seedlings**

ANOVA showing mean number of leaf of La Mé seedlings

Variate: Number of leaf

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	0.7952	0.3976	2.74	
Treatment	6	71.0335	11.8389	81.44	<.001
Month	3	168.8177	56.2726	387.11	<.001
Treatment. Month	18	5.3896	0.2994	2.06	0.021
Residual error	54	7.8498	0.1454		
Total	83	253.8858			

ANOVA showing mean leaf width of La Mé seedlings

Variate: Leaf width

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	8.6791	4.3396	10.15	
Treatment	6	231.5207	38.5868	90.24	<.001
Month	3	666.8784	222.2928	519.86	<.001
Treatment. Month	18	11.6982	0.6499	1.52	0.119
Residual error	54	23.0905	0.4276		
Total	83	941.8670			

ANOVA showing mean leaf length of La Mé seedlings

Variate: Leaf length

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	74.737	37.368	8.39	
Treatment	6	1523.418	253.903	57.03	<.001
Month	3	2278.725	759.575	170.60	<.001
Treatment. Month	18	98.832	5.491	1.23	0.270
Residual error	54	240.423	4.452		
Total	83	4216.136			

ANOVA showing mean seedling height of La Mé seedlings

Variate: Seedling height

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	44.753	22.376	3.23	
Treatment	6	2664.812	444.135	64.16	<.001
Month	3	4605.816	1535.272	221.78	<.001
Treatment. Month	18	216.597	12.033	1.74	0.061
Residual error	54	373.811	6.922		
Total	83	7905.789			

ANOVA showing mean bole diameter of La Mé seedlings

Variate: Bole diameter

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	8.405	4.202	1.48	
Treatment	6	1653.034	275.506	97.33	<.001
Month	3	3404.351	1134.784	400.88	<.001
Treatment. Month	18	123.774	6.876	2.43	0.006
Residual error	54	152.858	2.831		
Total	83	5342.422			

**ANOVA showing the interaction between OPRI & La Mé seedlings**

Variate: Mean number of leaf

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	1.4223	0.7112	3.56	
Variety	1	14.4789	14.4789	72.48	< .001
Treatment	6	46.3431	7.7238	38.67	< .001
Month	3	258.3022	86.1007	431.03	<.001
Variety. Treatment	6	30.5113	5.0852	25.46	<.001
Variety. Month	3	8.6944	2.8981	14.51	< .001
Treatment. Month	18	4.3349	0.2408	1.21	0.269
Variety. Treatment. Month	18	2.4649	0.1369	0.69	0.819
Residual error	110	21.9733	0.1998		
Total	167	388.5253			

Variate: Mean leaf width/cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	4.735	2.368	2.12	
Variety	1	0.759	0.759	0.68	0.411
Treatment	6	117.011	19.502	17.49	< .001
Month	3	1348.919	449.640	403.29	<.001
Variety. Treatment	6	141.431	23.572	21.14	<.001
Variety. Month	3	1.136	0.379	0.34	0.797
Treatment. Month	18	11.929	0.663	0.59	0.897
Variety. Treatment. Month	18	28.900	1.606	1.44	0.127
Residual error	110	122.642	1.115		
Total	167	1777.463			

Variate: Mean leaf length /cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	21.715	10.858	1.83	
Variety	1	54.572	54.572	9.20	0.003
Treatment	6	816.504	136.084	22.95	<.001
Month	3	4258.248	1419.416	239.34	<.001
Variety. Treatment	6	736.539	122.756	20.70	<.001
Variety. Month	3	28.166	9.389	1.58	0.198
Treatment. Month	18	58.815	3.267	0.55	0.926
Variety. Treatment. Month	18	63.880	3.549	0.60	0.894
Residual error	110	652.371	5.931		
Total	167	6690.809			

Variate: Mean seedling height /cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	39.237	19.618	2.03	
Variety	1	18.607	18.607	1.92	0.168
Treatment	6	1626.748	271.125	28.02	<.001
Month	3	8529.000	2843.000	293.84	<.001
Variety. Treatment	6	1115.874	185.979	19.22	<.001
Variety. Month	3	37.468	12.489	1.29	0.281
Treatment. Month	18	146.096	8.116	0.84	0.65
Variety. Treatment. Month	18	106.396	5.911	0.61	0.884
Residual error	110	1064.285	9.675		
Total	167	12683.712			

Variate: Mean bole diameter

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	1.494	0.47	0.23	
Variety	1	138.2.12	138.212	42.82	<.001
Treatment	6	1143.576	190.596	59.05	<.001
Month	3	6053.679	2017.893	625.19	<.001
Variety. Treatment	6	593.765	98.961	30.66	<.001
Variety. Month	3	35.142	11.714	3.63	0.015
Treatment. Month	18	80.809	4.489	1.39	0.150
Variety. Treatment. Month	18	69.560	3.864	1.20	0.276
Residual error	110	355.044	3.228		
Total	167	8471.282			

**ANOVA showing the effect of compost on root volume and dry matter yield**

**ANOVA showing mean root volume of OPRI seedlings**

Variate: Root volume

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	54.38	27.19	0.42	
Treatment	10	1169.14	116.91	1.80	0.127
Residual	20	1301.45	65.07		
Total	32	2524.97			

**ANOVA showing mean dry matter yield (DMY) of OPRI seedlings**

Variate: Dry matter yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	65.74	32.87	1.62	
Treatment	10	315.42	31.54	1.55	0.194
Residual	20	406.82	20.34		
Total	32	787.98			

**ANOVA showing mean root volume of LaMe seedlings**

Variate: Root volume

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	312.67	156.33	3.67	
Treatment	6	2093.24	348.87	8.19	0.001
Residual	12	511.33	42.61		
Total	20	2917.24			

**ANOVA showing mean dry matter yield (DMY) of LaMe seedlings**

Variate: Dry matter yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	56.16	28.08	0.95	
Treatment	6	2521.56	420.26	14.25	<.001
Residual	12	353.79	29.48		
Total	20	2931.52			

**ANOVA showing interaction of mean root volume of OPRI & LaMe seedlings****Variate: Root volume**

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	112.00	56.00	0.88	
Variety	1	288.10	288.10	4.53	0.043
Treatment	6	1753.62	292.27	4.60	0.003
Variety. Treatment	6	787.90	131.32 <sub>w</sub>	2.07	0.092
Residual error	26	1652.67	63.56		
Total	41	4594.29			

**ANOVA showing interaction of mean dry matter yield (DMY) of OPRI & LaMe seedlings****Variate: Dry matter yield**

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	87.80	43.90	1.59	
Variety	1	174.58	174.58	6.32	0.018
Treatment	6	1497.14	249.52	9.03	<.001
Variety. Treatment	6	1050.99	175.17	6.34	<.001
Residual error	26	718.17	27.62		
Total	41	3528.68			

**ANOVA showing the effect of compost on nutrient uptake****OPRI oil palm seedlings****Variate :N %**

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	3.4651	1.7325	5.65	
Treatment	10	7.7818	0.7782	2.54	0.012
Plant part	2	22.2117	11.1059	36.21	<.001
Treatment .Plant part	20	7.5394	0.3770	1.23	0.261
Residual	64	19.6283	0.3067		
Total	98	60.6263			

**Variate :P %**

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	0.13702	0.06851	0.98	
Treatment	10	0.49914	0.04991	0.71	0.709
Plant part	2	0.30891	0.15445	2.20	0.119
Treat.Plantpart	20	1.14156	0.05708	0.81	0.687
Residual	64	4.48323	0.07005		
Total	98	6.56987			

**Variate :K %**

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	0.1500	0.750	0.36	
Treatment	10	7.0000	0.7000	3.39	0.001
Plant part	2	11.2746	5.6373	27.34	<.001
Treat.Plantpart	20	6.6112	0.3306	1.60	0.080
Residual	64	13.1986	0.2062		
Total	98	38.2345			

Variate :Ca %

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	0.003541	0.001771	0.79	
Treatment	10	0.036929	0.003693	1.65	0.114
Plant part	2	0.772008	0.366004	171.97	<.001
Treat. Plant part	20	0.040859	0.002043	0.91	0.576
Residual	64	0.143659	0.002245		
Total	98	0.996996			

Variate :Mg %

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	0.00416	0.00208	0.19	
Treatment	10	0.34805	0.03481	3.20	0.002
Plant part	2	0.88807	0.44404	40.80	<.001
Treat.Plant .part	20	0.20822	0.01041	0.96	0.523
Residual	64	0.69657	0.01088		
Total	98	2.14507			

La Mé oil palm seedlings

Variate :N %

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	1.3956	0.6978	4.02	
Treatment	6	8.6756	1.4459	8.32	<.001
Plant part	2	19.8756	9.9378	57.19	<.001
Treat.Plantpart	12	4.3378	0.3615	2.08	0.042
Residual	40	6.9511	0.1738		
Total	62	41.2356			

Variate : P %

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	0.026393	0.013196	1.44	
Treatment	6	0.270805	0.045134	4.93	<.001
Plant part	2	0.026236	0.013118	1.43	0.251
Treat.Plantpart	12	0.158569	0.013214	1.44	0.187
Residual	40	0.366195	0.009155		
Total	62	0.848198			

Variate :K %

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	0.1171	0.0586	0.22	
Treatment	6	5.1389	0.8565	3.29	0.010
Plant part	2	8.5908	4.2954	16.48	<.001
Treat.Plantpart	12	6.0675	0.5056	1.94	0.058
Residual	40	10.4276	0.2607		
Total	62	30.3419			

Variate :Ca %

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	0.002143	0.001072	0.43	
Treatment	6	0.090972	0.015162	6.09	<.001
Plant part	2	0.936901	0.468451	188.29	<.001
Treat.Plantpart	12	0.100247	0.008354	3.36	0.002
Residual	40	0.099516	0.002488		
Total	62	1.229779			

Variate :Mg %

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	0.05754	0.02877	2.71	
Treatment	6	0.08327	0.01388	1.31	0.276
Plant part	2	0.62184	0.31092	29.29	<.001
Treat.Plantpart	12	0.26453	0.02204	2.08	0.042
Residual	40	0.42463	0.01062		
Total	62	1.45182			

**ANOVA showing interaction of nutrient uptake between OPRI & La Mé seedlings**

Variate: %Nitrogen uptake

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	3.3797	1.6898	7.30	
Variety	1	15.7870	15.7870	68.16	<.001
Treatment	6	4.0063	0.6677	2.88	0.013
Plantpart	2	36.4578	18.2289	78.70	<.001
Variety. Treatment	6	8.1308	1.3551	5.85	<.001
Variety. Plant part	2	0.5644	0.2822	1.22	0.301
Treatment. Plant part	12	4.1689	0.3474	1.50	0.141
Variety. Treatment. Plant part	12	4.3111	0.3593	1.55	0.123
Residual error	82	18.9937	0.2316		
Total	125	95.7997			

Variate: % Phosphorus uptake

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	0.014220	0.007110	0.80	
Variety	1	0.025418	0.025418	2.86	0.095
Treatment	6	0.237219	0.039537	4.44	<.001
Plant part	2	0.044417	0.022209	2.50	0.089
Variety. Treatment	6	0.083056	0.13843	1.56	0.171
Variety. Plant part	2	0.007812	0.003906	0.44	0.646
Treatment. Plant part	12	0.177028	0.014752	1.66	0.092
Variety. Treatment. Plant part	12	0.082932	0.006911	0.78	0.672
Residual error	82	0.729668	0.008898		
Total	125	1.401771			

Variate: % Potassium uptake

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	0.0340	0.0170	0.07	
Variety	1	0.7545	0.7545	2.95	0.090
Treatment	6	8.1989	1.3665	5.34	<.001
Plant part	2	14.0304	7.0152	27.41	<.001
Variety. Treatment	6	1.1478	0.1913	0.75	0.613
Variety. Plant part	2	0.4168	0.2084	0.81	0.446

Treatment. Plant part	12	3.9674	0.3306	1.29	0.239
Variety. Treatment. Plant part	12	5.7282	0.4773	1.87	0.051
Residual error	82	20.9831	0.2559		
Total	125	55.2610			

Variate: % Calcium uptake

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	0.001647	0.000823	0.34	
Variety	1	0.023302	0.023302	9.54	0.003
Treatment	6	0.043873	0.007312	2.99	0.011
Plant part	2	1.421439	0.710720	291.07	<.001
Variety. Treatment	6	0.067326	0.011221	4.60	<.001
Variety. Plant part	2	0.036312	0.018156	7.44	0.001
Treatment. Plant part	12	0.066394	0.005533	2.27	0.015
Variety. Treatment. Plant part	12	0.052022	0.004335	1.78	0.066
Residual error	82	0.200226	0.002442		
Total	125	1.912541			

Variate: % Magnesium uptake

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr.
Block stratum	2	0.017417	0.008709	0.96	
Variety	1	0.012046	0.012046	1.33	0.252
Treatment	6	0.166873	0.027812	3.08	0.009
Plant part	2	1.195347	0.597674	66.17	<.001
Variety. Treatment	6	0.134981	0.022497	2.49	0.029
Variety. Plant part	2	0.010960	0.005480	0.61	0.548
Treatment. Plant part	12	0.208412	0.017368	1.92	0.043
Variety. Treatment. Plant part	12	0.149904	0.012492	1.38	0.191
Residual error	82	0.740701	0.009033		
Total	125	2.636642			