African Journal of Agricultural Research Vol. 2 (12), pp. 656-662, December 2007
Available online at http://www.academicjournals.org/AJAR
ISSN 1991-637X © 2007 Academic Journals

Full Length Research Paper

The environmental impact of palm oil mill effluent (pome) on some physico-chemical parameters and total aerobic bioload of soil at a dump site in Anyigba, Kogi State, Nigeria

Okwute, Loretta Ojonoma* and Isu, Nnennaya R.

Department of Biological Sciences, University of Abuja, Abuja, Nigeria.

Accepted 22 October, 2007

The effect of POME on the integrity of the soil was investigated. Soil samples from the palm oil mill effluent (POME) dumpsite as well as a non-POME site were tested for physico-chemical properties such as pH, water holding capacity, available phosphorus, organic carbon, total nitrogen, mineral assay and cation exchange capacity. Furthermore, the total aerobic bacteria counts of the samples at 2, 30 and 40°C were assayed. Results showed significant differences ($P \leq 0.05$) and ($P \leq 0.01$) in pH, water holding capacity, organic carbon, total nitrogen, cation exchange capacity and available phosphorus. 30°C had the highest average microbial bioload ($1.64 \times 10^9 \pm 0.2$) and so, the most favourable for growth. Bacterial counts from the POME dumpsite were found to be significantly higher ($P \leq 0.05$), ($9.6 \times 10^8 \pm 0.1$ at 20°C, $1.64 \times 10^9 \pm 0.2$ at 30°C and $1.07 \times 10^9 \pm 0.2$ at 40°C) than the counts for the non-POME soil sites ($4.5 \times 10^8 \pm 0.3$ at 20°C, $7.6 \times 10^8 \pm 0.3$ at 30°C and $5.9 \times 10^8 \pm 0.3$ at 40°C) at all the temperatures. The implications of these results on soil environment are discussed.

Key words: Environmental impact, POME, total aerobic bacteria.

INTRODUCTION

Palm oil processing is carried out using large quantities of water in mills where oil is extracted from the palm fruits. During the extraction of crude palm oil from the fresh fruits, about 50% of the water results in palm oil mill effluent (POME). It is estimated that for 1 tonne of crude palm oil produced, 5 - 7.5 tonnes of water ends up as POME (Ahmad et al., 2003). The solid waste products that result from the milling operation are empty fruit bunches, palm fibre, and palm kernel. In both traditional and modern milling settings, these solid waste products are all put to economically useful purposes such as fuel material and mulch in agriculture. It is the POME that is usually discharged into the environment, either raw or treated.

Raw POME consisting of complex vegetative matter is thick, brownish, colloidal slurry of water, oil and solids including about 2% suspended soils originating mainly from cellulose fruit debris, that is, palm mesocarp (Bek-Nielsen et al., 1999). The raw or partially treated POME has an extremely high content of degradable organic matter, which is due in part to the presence of unrecovered palm oil (Ahmad et al., 2003). This highly polluting wastewater can, therefore, cause pollution of waterays due to oxygen depletion and other related effects as reported by Ahmad et al. (2003). Thus, while enjoying a most profitable commodity, palm oil, the adverse environmental impact from the palm oil industry cannot be ignored.

It has been observed that most of the POME produced by the small-scale traditional operators undergoes little or no treatment and is usually discharged into the surrounding environment. The local palm fruit processing method to produce palm oil is very long and laborious. Firstly, the palm bunches are quartered (cut into four) and left overnight for easy separation of nuts from the spikelets. The

---

*Corresponding author. E-mail: lolookwute@yahoo.com. Phone: +2348065261042.

The fruits are boiled for 1-1½ h, pounded in a mortar or macerated with feet in a canoe-like container, water is added and it is well mixed up. All nuts are then carefully removed by hand. The fibres are well shaken over in the sludge, until oily foam comes up to the surface of the sludge. The foam is collected in a container until the operation is completed when there is no more foam formation. This foam is later boiled for about 30 to 40 min. The clean edible oil then collects on the surface leaving the sludge at the bottom. Sometimes the oil in the sludge pit is recovered and mixed with fibre to make a fire starting cake called flint. At other times, the sludge is poured onto the surrounding bushes and soil together with the liquid waste known as palm oil mill effluent (POME).

Large and medium scale mills produce copious volumes of liquid waste (POME) from the processing lines, (sterilizers, clarifying centrifuges and hydro cyclones) when POME is produced on a large and commercial level. However effective the system of oil recaptured from the sludge may be; the POME discharged from an oil mill is objectionable and could pollute streams, rivers or surrounding land (Hartley, 1988). While mills were comparatively few and mostly beside large fast flowing rivers, the problem was not a serious one but the situation in many countries including Nigeria is quite different with much attention being recently given to the subject of effective disposal and protection of the environment. Apart from the sludge water itself which amounts to about 300 kg/tonne of bunches milled (or about 1.5 tonne/ tonne of palm oil), there are also about 175 kg of sterilizer condensate and between 40 and 140 kg of POME from the hydrocyclone or clay bath separators / tonne of bunches (Hartley, 1988). The total amounts of POME is therefore more than a tonne / tonne bunches or 2.5 tonne of oil produced. In milling 20 tonnes of bunches / hour, more than 200 tonnes of POME may be discharged over 24 h and this may contain up to I tonne of oil and 9 tonnes of dissolved or suspended solids (Hartley, 1988).

Malaysia is the largest producer and exporter of palm oil in the world (Ahmad et al., 2003). In Malaysia, the palm oil industry contributes 83% of the single largest polluter, the situation is probably similar in other palm oil producing countries (Kwon et al., 1989), and so raises the need to look at the effect of raw POME on the environment in Nigeria. The constituents of raw POME have been reported to be a colloidal suspension of 95 - 96% water, 0.6 - 0.7% oil and 4 - 5% total solids including 2 - 4% suspended solids (Ahmad et al., 2003). The raw POME has an extremely high content of degradable organic matter, which is due in part to the presence of unrecovered palm oil, thus, POME should be treated before discharge to avoid serious environmental pollution. Raw POME has Biological Oxygen Demand (BOD) values averaging around 25,000 mg/litre, making it about 100 times more polluting than domestic sewage Maheswaran and Singam, 1977). In terms of its population equivalent, the BOD generated by the palm oil industry in Malaysia in 1998 is equivalent to that generated by 38 million people (Bek-Nielsen et al., 1999). Prior to 1978, the oxygen depleting raw POME was freely discharged into public waterways adversely affecting aquatic life and water quality (Bek-Nielsen et al., 1999). To mitigate the problem, the Malaysian government promulgated the Environ-ental Quality (Prescribed Premises) (Crude Palm Oil) Regulations 1997 (Amendment of 1982), (Department of Environment, Malaysia, 1999), which requires mills to treat their effluent to a BOD of 100 mg/litre or lower before water course discharge and below 5,000 mg/litre for land application.

In Malaysia, the enforcement of strict laws promulgated under the Environmental Quality Act has led to the development of several innovative technologies for the utilization of POME. Many methods of attaining the required standards and utilizing the effluent to advantage, have been tried by many researchers including Davis (1978), Chan et al. (1980), Dolmat et al. (1987), Bek-Nielsen et al. (1999) and more recently, Ahmad et al. (2003). These methods include tank digestion and mechanical aeration, tank digestion and facultative ponds, the decanter-drier system, aerobic and facultative ponds and distillation ponds.

In Nigeria, palm oil effluent is discharged into the environment in its raw form especially by small-scale ope-ators. This study is based on the palm oil producing town of Anyigba, which is a central Igala town in the eastern flank of Kogi State in central Nigeria. The abundance of palm trees in the area makes the large production of palm oil and Igala's most important crop a natural source of livelihood for most families (Agi, 1980). The bulk of the exports of palm produce in Igalaland comes from individual homesteads scattered throughout the area and the industry is a true example of a cottage system. The production line is basically traditional involving rudimentary equipment and the division of labour and tasks closely integrated with the domestic routine of a basically agricultural economy. While the men mainly help with the harvesting of the palm fruit from the trees, the women fully take care of the processing of the fruits, oils and sales. Very few people possess and can afford the hydraulic hand press and so most times, the processing method is local and traditional which is handed down from generation to generation. Generally, homesteads in Anyigba are dotted with processing sites and facilities all the year through.

According to the Produce Department of the Ministry of Agriculture, Kogi State, approximately 3,600 metric tonnes of palm oil is produced in the state on a yearly basis (Lawal, 2004). This is apart from those smuggled away, consumed locally and not recorded. The above figure is based upon what is brought to the market for sale so the actual amount may be much more than that. Unfortunately, there seems to be a dearth of literature on the

the effects of POME on the environment in Nigeria. This paper therefore, aims at studying the general impact of POME in the effluent dumpsite on some physico-chemical properties, pH, soil texture, water holding capacity, organic carbon, total nitrogen, e.t.c. of the soil.

MATERIALS AND METHODS

MATERIALS

Chemicals and reagents: All reagents used in the different analyses were of analytical grade from BDH Chemicals and were used without further purification.

Media and sterilization

All glassware and media used were sterilized by autoclaving at 121°C for 15 min at 15 pounds pressure and air-drying in the hot air oven at 160°C for 2 h.

Sampling

First, a visual inspection of the sampling sites was conducted and the differences between the sites in terms of vegetation, presence of constitution, soil colour, odour, e.t.c. were observed and noted. Sampling was done four times from four sites i.e. a site about 10 yards before the effluent dumpsite (A), the effluent dumpsite (B), a site about 10 yards after the dumpsite (C) and a non-effluent site (D), about 10 yards away from site C which had no effluent dumped on it at all and so, served as control according to the method described by Wollum (1982). The samples were air-dried or oven-dried (as required by the test), crushed to finer particles and sieved using a 2mm sieve and then stored in fresh clean polyethylene bags in the refrigerator at 2°C between 7-14 days so as to maintain the stability of samples without significant alteration in their biological properties (Clark, 1965). Sampling was repeated after 14 days.

Particle size and textural class

In carrying out this test, the hydrometer method described by Bouyoucous (1951) and Agbenin (1995) was used. The procedure was the same for all the soil samples. After the values for silt and clay were determined, the value of sand was obtained by subtracting the values of silt and clay from 100.

Soil pH

Soil pH was measured out by the potentiometric method as described by Brady and Weil (1990). A glass electrode Testronic digital pH meter (Model 511) was used for the measurement.

Water holding capacity

Water holding capacity was carried out by the Core method described by Agbenin, (1995).

Organic carbon

Organic Carbon measurement was carried out by the method of Kalembasa and Jenkinson (1973)

Total nitrogen

Total Nitrogen assay was carried out by the Kjeldahl method as described by Bremner and Mulvaney (1982).

Available phosphorus

Available phosphorus was determined by the method described by I.I.T.A. (1979) and Olsen and Sommers (1982).

Exchangeable cations

This was determined according to the method described by I.I.T.A. (1979) and Agbenin (1995). A flame photometer (FP 640) was used in the determination.

Cation exchange capacity

This was determined by the summation of the cubic centimetre (cm^3) values of the exchangeable cations of each sample determined above.

Total aerobic bacterial population count

This was carried out by the method of Wollum (1982) and involved the use of nutrient agar (International Diagnostic Group) modified with 0.05g/litre of *Nystatin* incorporation to prevent the growth of fungi. Plating was done in triplicates for each dilution by the spread plate technique. Inoculated plates were inverted and incubated at 3 different temperatures, 20, 30 and 40°C for a maximum of 72 h.

Statistical analysis

Data generated from the study were analyzed using the parametric test of analysis of variance (ANOVA), at $P \leq 0.05$ and $P \leq 0.01$ confidence limits for all the sample sites and parameters and particularly for the POME and non-POME sites.

RESULTS

Table 1 shows the different visual characteristics of the 4 soil samples.

The Table 2 shows the textural class of each soil sample, which indicates the percentage of sand, silt and clay.

The results of the tests for the effect of POME on the physico-chemical properties of all the soil sites assessed are presented on Table 3.

Table 4 shows the counts of total aerobic bacteria in the 4 soil samples at 3 different temperatures.

DISCUSSION

The first impression that could be got from the POME soil environment was that of barrenness and a wasted land. POME was also said not to respond to ordinary treatment as in the case of municipal or domestic effluents because of the high density of suspended solids (Thilaimuthu, 1976). It was observed that within a few days after a POME application by sprinklers, soft weeds on the

Table 1. Visual characteristics of the soil samples.

Characteristics	Site A	Site B	Site C	Site D
Vegetation	Little vegetation	Bare without vegetation	Little vegetation	Grown with weeds
Colour	Brown	Black with humus	Dark brown	Brown and Sandy
Moisture	Dry	Damp	Little moisture	Dry
Odour	Free of odour	Odorous	Slight odour	Free of odour
Constitution	Free of debris	Debris from oil processing	Presence of some debris	Free of debris

Site A = 10 yards before POME site (B)
Site B = POME dump site
Site C = 10 yards after POME site
Site D = 10 yards after C (non-POME)

Table 2. Particle size analysis/textural class

Sample description	% silt	% sand	% clay	Textural class
SITE A	30.00	40.60	29.40	SCL
SITE B	22.00	50.40	27.60	SCL
SITE C	12.60	60.00	27.00	SL
SITE D	6.00	66.40	27.60	SL

SCL - Sandy Clay Loam
SL - Sandy Loam

Table 3. Physico–chemical parameters of the soil samples.

Parameters	Sampling sites			
	A	B**	C	D
Soil pH	3.29 ± 0.01	$6.59 \pm 0.01^{**}$	5.60 ± 0.01	3.57 ± 0.01
% Water Holding Capacity (WHC)**	20.40 ± 0.01	$37.29 \pm 0.01^{**}$	29.50 ± 0.01	22.33 ± 0.01
%Organic Carbon	2.10 ± 0.01	$3.39 \pm 0.01^{**}$	3.00 ± 0.01	2.31 ± 0.01
%Total Nitrogen	13.10 ± 0.01	$13.53 \pm 0.01^{*}$	13.38 ± 0.01	13.19 ± 0.01
Available Phosphorus (ppm)	20.50 ± 0.01	$26.30 \pm 0.01^{*}$	23.50 ± 0.01	21.0 ± 0.01
Exchangeable Cations (cm^3)				
a) Potassium	5.50	11.02**	8.40	4.90
b) Sodium	1.00	1.40	1.20	0.90
c) Calcium	8.50	10.00*	8.00	7.00
d) Magnesium	8.89	9.00	9.00	9.00
Cation Exchange Capacity (CEC)**	22.40	31.42**	26.80	21.80

A = before POME site
B = effluent site
C = after effluent site
D = non-effluent site
Values are means of quaduplet results ± standard error.
* - shows significant difference at 99% confidence limit ($P \leq 0.01$).
** - shows significant difference at 95% confidence limit ($P \leq 0.05$).

Table 4. Total aerobic bacterial count at different temperatures.

Temperatures	Sampling sites			
	A	B**	C	D
20°C	$3.5 \times 10^8 \pm 0.1$	$9.6 \times 10^8 \pm 0.1^{*}$	$6.5 \times 10^8 \pm 0.3$	$4.5 \times 10^8 \pm 0.3$
30°C**	$7.0 \times 10^8 \pm 0.1$	$1.64 \times 10^9 \pm 0.2^{**}$	$1.24 \times 10^9 \pm 0.2$	$7.5 \times 10^8 \pm 0.3$
40°C	$6.5 \times 10^8 \pm 0.1$	$1.07 \times 10^9 \pm 0.2^{**}$	$8.3 \times 10^8 \pm 0.3$	$5.9 \times 10^8 \pm 0.3$

Values are means of quaduplet results ± standard deviation.
* - shows significant difference at 99% confidence limit ($P \leq 0.01$)
** - shows significant difference at 95% confidence limit ($P \leq 0.05$)

ground were killed and suppressed and took about 2 - 3 months to regenerate (Huan, 1987). Some of those earlier views have however, been modified as POME has been known to be non-toxic and bio-degradable (Hemming, 1977; Bek-Nielsen et al., 1999).

Physico-chemical parameters

Soil pH and textural class

It has been reported that when raw POME is discharged the pH is acidic (Hemming, 1977) but seems to gradually increase to alkaline as biodegradation takes place. In this study however, the non-POME soil (control) as can be seen in Table 3 is acidic (pH = 3.57) and supported plant growth the POME soil was near basic (pH = 6.59) and did not support any evident plant growth. In terms of pH therefore, the POME soil was significantly different ($P \leq 0.05$) from the non-POME. Many of the soils of the world are affected by excess acidity, a problem exacerbated by heavy fertilization with certain nutrients and by acid rain (Paul and Clarke, 1989). pH is said to increase with increasing soil depth (Skyllberg, 1993). The sample was taken from about 0-15cm depth of the soil, which contained already degrading POME and the dumping of POME was continuous, which may have been responsible for the pH of 6.59 as seen in Table 3.

Soil acidity (pH) is one of the principal factors affecting nutrient availability to plants. Therefore, the availability of plant nutrients in soils is affected by the soils' pH. The major nutrients (nitrogen, potassium and phosphorus) cannot effectively promote high crop yields if the soil pH is not correct. At pH values less than approximately 5.5, toxic levels of these elements may be present in the soil. Soils have a near-neutral pH (unless the soil is used to growing acid loving crops). The non-POME soil studied in this research was at variance with this norm but reasons for this could not be easily ascertained apart from nature. Most crops grow at a pH between 6.5 and 7.5 (Hajek et. al, 1990).

The textural class of the site before the POME soil and the POME soil was sandy clay loam (SCL) as can be seen in Table 2 while that after the POME and the non-POME soil was sandy loam (SL) (Table 2) which was expected because of the proximity of the sites to each other. The different textural classes may also be explained by the higher organic matter content (Tables 1 and 3). Major factors are the water, unrecovered oil and cellulose fruit debris (higher organic matter) of the POME soil when compared to the non-POME, which was probably why the POME soil retained more water (Bek-Nielsen et al., 1999). The absence of vegetation was not surprising since the POME soil's ability to retain water could cause clogging of soil pores and hence water logging of the soil (Chan et al., 1980). Excess water in soil restricts micro–organisms and their activities by preventing oxygen movement into and through the soil in sufficient quantity to meet the oxygen demand of the organisms (Paul and Clarke, 1989).

Water holding capacity, org. carbon and total nitrogen

It was observed that the water holding capacity, organic carbon and total nitrogen for all the sites were significantly different ($P \leq 0.05$) from each other for all the samples with water holding capacity of the soil samples being the most significantly different ($P \leq 0.05$). The POME site was the most statistically significant site ($P \leq 0.05$) for the 3 parameters followed by the site immediately after, the non-POME and then the site before. The reason for this was not far-fetched as Site B was the POME site and so, was the most altered when compared to the control (non-POME). The organic carbon content in the POME soil (3.39%) was significantly higher than the non-POME soil (2.31%) ($P \leq 0.05$) while total nitrogen of POME soil was significantly higher (13.53%) than the value for the non-POME (13.19%) at $P \leq 0.01$.

The organic matter of a soil is usually determined and reported as a measure of the organic carbon concentration in the soil as reported by Nelson and Sommers (1982). Organic matter content strongly affects the soil fertility by increasing the availability of plant nutrients, improving the soil structure and the water holding capacity and also acting as an accumulation phase for toxic, heavy metals in the soil environment (Deiana et al., 1990). For this reason, the recycling of organic wastes through their application to the soil can be an important promising practice for agricultural activities.

The organic carbon and total nitrogen contents of the POME and non-POME samples (Table 3) showed a significant difference ($P \leq 0.05$) while there was no statistical difference between the non-POME site and the site before the POME site as their values are very close; 2.31 and 2.01. The higher organic carbon and increased nitrogen content observed in the POME soil in this study correlate with the findings of Wood (1977), Huan (1987), Dolmat et al. (1987) and Acea and Carballas (1996). The higher organic carbon value for the POME soil can be related to the constituents of raw and untreated POME. It is possible that a slow decomposition of organic matter in POME under water-saturated conditions, particularly when mean soil temperatures are low (Batjes, 1996) contributed significantly to the higher organic carbon of the POME soil.
STOP

Exchangeable cations and cation exchange capacity

According to Rhoades (1982), cation exchange capacity (CEC) usually expressed in milliequivalents/100 grams of soil, is a measure of the quantity of readily exchangeable cations neutralizing negative charges in the soil. The CEC values observed in this study when considered along with the exchangeable cations was significantly higher ($P \leq 0.05$) in the POME than the non-POME soil. In a similar study (Oviasogie and Aghimien, 2002), the results showed an overall increase in the CEC of POME soils especially at the area close to the source of the POME and agree with the observation in this study. The results showed enrichment of the soils in phosphorus, nitrogen, calcium, magnesium, sodium and potassium due to the application of POME. The increase in CEC could be attributed to the increase in the pH dependent charge as well as the addition of organic matter from the effluent as observed by Huan, (1987). Lim and P'ng (1983) also recorded increase in pH, potassium, calcium, magnesium and organic matter content with the application of POME to soil.

Available phosphorus

The POME soil was observed to be richer in phosphorus than the non-POME soil. In fact, there was a significant difference ($P \leq 0.01$) in phosphorus values of the POME-treated soil over that of non-POME as can be seen in Table 3. This agrees with the findings of Wood (1977) and Huan (1987). There is good evidence that suggests that phosphorus is the dominant element controlling carbon and nitrogen immobilization (Paul and Clarke, 1989). The increase in the available phosphorus in the POME soil suggested a possibly high absorption in the soil or a possible precipitation of phosphate (Huan, 1987). This may be due to the gradual biodegradation of POME, which leads to a delayed effect on the soil.

Total aerobic bioload

The total aerobic bacterial bio-load of the POME and non-POME soils were significantly different ($P \leq 0.05$) at all the temperatures and in all the soil sites sampled. A combination of the two factors (sites and temperature) also showed a significant difference at 95% confidence limit. There was a significant difference between the bio-load of the site before the POME soil and that immediately after ($P \leq 0.05$). In terms of temperature, 30^0C had the highest average microbial bioload ($1.64 \times 10^9 \pm 0.2$), which implies that in this study, it was the most favourable temperature for the proliferation of the bacterial flora ($P > 0.05$). There was no statistical difference between site before the POME soil and the non-POME soil. However, the bacterial bioload of the POME soil was significantly higher than that of the non-POME soil ($P \leq 0.05$) and may be attributed to higher organic matter in the POME and a more favourable pH.

Untreated POME contains high concentrations of free fatty acids, starches, proteins and plant tissues (Bek-Nielsen et al., 1999) and also non-toxic (Ma and Ong, 1982; Ngan et al., 1996). Organic matter plays an important role in soil productivity and the solids in raw POME are good sources of organic matter as observed in this work (Chan et al., 1980). Numerous organisms invade and grow in POME breaking down complicated molecules into simple ones. The high organic matter in palm oil effluent, which has been shown to be higher than control soil samples in previous research work (Wood, 1977), may have a major role in the proliferation of aerobic micro – organisms.

Conclusion

From the data generated in this study, it is obvious that the physico-chemical properties of soil at the POME dump site were altered. Since POME has been shown to be acidic in nature, it is advisable that it undergoes some form of treatment or decomposition before application as manure or on land taking into cognizance the physico-chemical properties of the land in that particular environment. With that, it may be possible to avoid the initial harsh effects of POME on soil meant for agriculture. The state of the soil in that environment will determine the best treatment for the effluent to be dumped on it. It is concluded that proper use and safe disposal of POME in the land environment could lead to improved soil fertility. Environmental pollution considerations in small-scale palm oil milling need better attention as this industrial segment assumes greater importance.

ACKNOWLEDGEMENT

The authors wish to sincerely thank Kogi State University for the facilities used in the course of this research work.

REFERENCES

Acea MJ, Carballas T (1996). Microbial response to organic amendments in a forest soil. Bioresource Technol. 57: 193-199.

Agbenin JO (1995). Laboratory manual for Soil and Plant Analysis (Selected methods and data analysis). Faculty of Agriculture/Institute of Agricultural Research, A.B.U. Zaria: 7-71.

Agi FI (1980). Oil palm improvement in Igalaland In: B. Dawtrey (ed.) Elaeis: A journal of Igalaland, 2 (2): 8-11.

Ahmad A, Ismail S, Bhatia S (2003). Water recycling from palm oil mill effluent (POME) using membrane technology. Desalination, 157:87-95.

Batjes NH (1996). Total carbon and nitrogen in the soils of the world. European J. of Soil Sci. 47 (2): 151-163.

Bek-Nielsen C, Singh G, Toh TS (1999). Bioremediation of palm oil mill effluent. In: Proceedings Porim International Palm Oil Congress 16th February 1999, Kuala Lumpur, Malaysia.

Bouyoucous CJ (1951). A recalibration of the hydrometer mechanical analysis of soil. Agron. J. 43: 434 – 438.

Brady, N.C. and Weil, R.R. (1990). The Nature and Properties of Soil 12th edition. Prentice-Hall Inc. p.363.

Bremner JM, Mulvaney CS (1982). Total nitrogen In: C.A. Black. (ed.) Methods of Soil Analysis, Part 2, Agronomy 9. American Society of Agronomy Inc. Madison, Wisconsin: pp.1149-1178.

Chan KW, Watson I, Lim KC (1980). Use of oil palm waste material for increased production. Paper presented at the Conference on Soil Science and Agricultural development in Malaysia, Kuala Lumpur, Malaysia.

Clark FE (1965). Agar-plate method for total microbial count. In: C.A. Black (ed.) Methods of Soil Analysis, Part 2, Agronomy 9. American

Society of Agronomy Inc. Madison, Wisconsin: pp.1460-1466.

Davis JB (1978). Palm oil mill effluent : a review of methods proposed for its treatment. Tropical Sci. 20: 233.

Deiana S, Gessa C, Manunza B, Rausa R, Sebeer R (1990). Analytical and spectroscopic characterization of humic acids extracted from sewage sludge, manure and worm compost. Soil Sci. 150 (1):419-426.

Department Of Environment, Malaysia (1999). Industrial processes and the environment. Crude Palm Oil Industry Handbook 3 :5-10.

Dolmat MT, Lim KH, Zakaria ZZ, Hassan AH (1987). Recent studies on the effects of land application of palm oil mill effluent on oil palm and the environment. In: Proceedings of International Oil Palm, Palm Oil Conferences Dr. B. Hj. Abdul Halim, Hassan Chew Poh Soon, B.J. Woond, Dr. E. PushParajah (eds.) 2:596 – 604.

Hajek BF, Karlen DL, Lowery B, Power JF, Schumaker TE, Skidmore, EL, Sojka T (1990). Erosion and Soil Properties In: W.E. Larson, G.R. Foster, R.R. Allmaras and G.M. Smith (eds.) Research Issues in Soil Erosion Productivity pp. 23-40.

Hartley CWS (1988). The products of the oil palm and their extraction. Oil Palm 3rd ed. Longman Scientific and Technical with John Wiley and Sons, Inc. New York: pp. 721-724.

Hemming ML (1977). A viable solution to the palm oil effluent problem. In: Proceedings of the Malaysian International Symposium on Palm Oil Processing and Marketing. D.A. Earp and W. Newall (eds.) Kuala Lumpur, 17-19th: pp. 79-95.

Huan KL (1987). Trials on long-term effects of application of POME on soil properties, oil palm nutrition and yields. In : Proceedings of the International Oil Palm, Palm Oil Conferences (eds.) Dr. B. Hj. Abdul Halim, Hassan Chew Poh Soon, B.J. Woond, Dr. E. PushParajah (eds.) 2:575 – 598.

International Institute For Tropical Agriculture (I.I.T.A.), (1979). Selected Methods for Soil And Plant Analysis, Manual Series. I.I.T.A. Ibadan (1): 4-12.

Kalembasa, S.J. and Jenkinson, D.S. (1973). *Soil Chemical Analysis.* Prentice-Hall Inc., New York : pp. 23-25.

Kwon GS, Kim BH, Ong ASH (1989). Studies on the utilization of palm oil wastes as the substrates for butanol fermentation. *Elaeis* 1 (2): 91-102.

Lawal G (2004). Produce department, Ministry of Agriculture, Kogi State. (Personal communication).

Ma AN, Ong, ASH (1982). Anaerobic digestion of palm oil mill effluent.PORIM Bulletin (4):24

Lim CA P'ng TC (1983). Land application of digested POME by sprinkler system. Proceedings of the seminar on land application of oil palm and rubber factory effluent. Serdang, October, 1983.

Maheswaran A, Singam G (1977). Pollution control in the palm oil industry– promulgation of regulations. *Planter* 53 : 470 – 476.

Nelson DW, Sommers LE (1982). Total carbon, organic carbon and matter. In: A. L. Page, R.H. Miller and D.R. Keeney (eds.) Methods of Soil Analysis, Part 2 Chemical and Microbiological Properties. Madison, Wisconsin pp. 539-579.

Ngan MA, Zajima Y, Asahi M, Junit H (1996). A novel treatment process for palm oil mill effluent. PORIM

Olsen SR, Sommers LE (1982). Phosphorus In: A. L. Page, R.H. Miller and D.R. Keeney (eds.) Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties. Madison, Wisconsin : pp. 403-430.

Oviasogie PO, Aghimien AE (2002). Macro nutrient status and speciation of Cu, Fe, Zn and Pb in soil containing palm oil mill effluent. Global J. of Pure and Applied Science. 9 (1): 71-80.

Paul EA, Clark FE (1989). Soil Microbiology and Biochemistry. Academic Press Incorporated San Diego, California.: pp.11-234.

Rhoades JD (1982). Cation exchange capacity. In: A. L. Page, R.H. Miller and D.R. Keeney (eds.) Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties. Madison, Wisconsin : pp.149-157.

Skyllberg U (1993). Acid-Base properties of humus layers in northern coniferous forests. Dissertation, Swedish University of Agricultural Sciences, Department of Forest Ecology. Soil Science section: 54.

Thilaimuthu J (1976). Extraction of sludge solids in palm oil effluent. Planter. 52 : 420-423.

Thomas GW (1982). Exchangeable Cations. In: A.L. Page, R.H. Miller and D.R. Keeney (eds.) Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties. Madison, Wisconsin. pp.159-165.

Wollum AG II (1982). Cultural methods for soil micro-organisms In : A.L. Page, R.H. Miller and D.R. Keeney (eds.) Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties. Madison, Wisconsin: pp. 781-801.

Wood BJ (1977). A review of current methods for dealing with palm oil mill effluents. Planter 53: 477-495.