

Investigation of soil related potential for sustainable growth and development of Oil Palm (*Elaeis quineensis* Jacq) in Nigeria

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Master's Thesis in Soil Science

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Investigation of soil related potential for sustainable growth and development of Oil Palm (*Elaeis guineensis* Jacq) in Nigeria

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Cover: Oil palm plantation in NIFOR main station in Edo State, 2011, photo by author.

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ABSTRACT

Seven representative soil sites at the Nigerian Institute for Oil Palm and Research (NIFOR) were studied to evaluate the present fertility status of the soils for sustainable production of palm oil and

in particular investigate the soil boron status. Profiles were sited at Edo State (Ed1, Ed2 and Ed3) and Akwa Ibom State (Akwa1, Akwa2, Akwa3 and Akwa4). Three of the sites were from Edo and four sites were from Akwa Ibom State. A total of 56 soil sample were analyzed, 24 soil samples from 24 layers in Edo State and 32 soil samples from 32 layers in Akwa Ibom State, with the same analytical treatments. Total annual precipitation amounts to about 1600-2000mm in Edo State, but 2000-4000, at Akwa Ibom State.

pH was measured at a 1:1 soil-water ratio using a pH meter, particle size analysis by the hydrometer method, organic carbon by wet-oxidation using the Walkey Black method, nitrogen by the macro Kjeldahl method, available phosphorus by the Bray II method, exchangeable base cations by the neutral ammonium acetate method, exchangeable acidity by normal potassium chloride, available boron by the azomethine-H colorimetric method and electrical conductivity by the electrode conductivity meter.

The soil texture was in general sandy with about 83 - 91% sand content at the Akwa Ibom State and 75 - 97% at the Edo State. The high sandy content implied low to moderate water retention capacity in most of the soils in the two regions. Soil colour values were dominantly dark grayish brown (2.5 Y 3/2) to black (2.5 Y 2/0). The soils were classified as plinthic arenosols in the Edo State and ferralic arenosols in the Akwa Ibom State. Most soil chemical parameters indicated a poor nutrient status.

All soils were acid with a low pH (4.2 – 6.3), and exchangeable acidity was predominately low with about 0.2 – 0.5 meq/100g soil at Edo State and predominately moderate to high 0.6 – 1.2 meq/100g soil at the Akwa Ibom State. The exchangeable Al was low with about 0.0 – 0.5 meq/ 100g soil at Akwa Ibom State. In general, there were no detectable levels of available Al at Edo State soils. The soil organic matter (measured as total organic carbon) was low with about 0.7 – 1.1% in the top 15cm soil layer at Edo State and 0.8 – 2.0% at Akwa Ibom State. Low organic matter content and high sand content resulted in low exchangeable cation capacities in both states. Thus, the silt and clay were somewhat higher at Akwa Ibom State than

at Edo State. In general there was a low electrical conductivity with about 8.3 – 33.9 $\mu\text{S}/\text{cm}$ at Edo State and 6.0 - 240 $\mu\text{S}/\text{cm}$ at the Akwa Ibom State.

A low total N with about 0.0 - 0.1% in the top 15cm soil layer at Edo State and 0.1 – 0.2% at Akwa Ibom State, low exchangeable Ca with about 0.5 – 2.2meq/100g soil at Edo State and 1.6 – 3.2 meq/100g at Akwa Ibom State thus the content of exchangeable Ca in Akwa Ibom State were more than that of Edo State. Low exchangeable Mg with about 0.1 – 0.6meq/100g soil at Edo State and 0.2 – 2.1 meq/100g soil at Akwa Ibom State, comparatively the contents of exchangeable Mg in Akwa State were more than that of Edo State. The exchangeable Na were low to high with about 0.1 – 0.4meq/100g soil at Edo State and 0.4 – 0.9meq/100g soil at Akwa State. In general the exchangeable sodium percentages were comparatively considered low with about 11.1 – 17.5% at Edo State and 7.1 – 35.8% at Akwa Ibom State.

Exchangeable K was comparatively low with about 0.0 – 0.1meq/100g soil at Edo State and 0.1 – 0.4meq/100g soil at Akwa Ibom State. In general exchangeable base cations were low with about 0.9 – 3.3meq/100g soil at Edo State and 1.9 – 5.6meq/100g soil at Akwa Ibom State. The base saturation was generally high with about 63 – 95% at Edo State and 69 – 98% at Akwa Ibom State. In general the Ca/K ratios were high with about 5.3 – 36.7 in Edo State and 7.1 – 56.4 at Akwa Ibom State. The Mg/K ratios were generally high with about 2.0 – 10.4 at Edo State and 1.1 – 34.7 at Akwa Ibom State. C/N ratios were low to high 6.0 – 19.0 at Edo State and 7.0 – 39.0 at Akwa Ibom State.

Available B was generally low with about 0.0 – 11.2mg/kg at Edo State and 0.0 – 5.3mg/kg at Akwa Ibom State. Available P was low with about 3.0 – 21.4mg/kg at Edo State and predominately high 5.6 – 83.5mg/kg at Akwa Ibom State. Generally, available P contents at Akwa Ibom State were higher than that of Edo State.

The low silt and clay contents, low pH, and low organic carbon, low concentration of exchangeable base cations levels were the major constraints of the soils for sustainable oil palm production. Thus the soils were placed in the S3 category regarded as marginally suitable for oil palm production.

Based on the fertility standards (FAO, 1976), the NIFOR soils were generally rated low in fertility despite the high levels of available P, Ca/K, Mg/K and base saturation.

Management measures to be adopted should include application of required levels of organic and inorganic fertilizers, since fertility standards were not met.

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1.0 INTRODUCTION

1.1 Palm Oil Breeding and Genetic

Oil palm (*Elaeis guineensis* Jacq) is a pinnate perennial tree crop grown in the tropical regions (Wilmanns and Bogenrieder, 1991; Corley and Tinker 2003; Anonymous. 2006a). According to Poku, (2002) the placenta of oil palm fruit is a sessile drupe and consists of various physiological pigmented parts which include; the exocarp (skin surface), mesocarp (fleshly), endocarp (hard stony shell) and kernel (seed)

According to Hartman *et al.*, (1993) the origin of oil palm is in the most southern part of Ghana and Nigeria. According to Hartley, (1988) the main West Africa wild belt of oil palm plantation also covers indigenous regions such as; Liberia, Ivory Coast, and Cameroon, Congo, Zaire and Sierra Leone republics.

There are four cultivars of *Elaeis guineensis* which have laid the foundation for oil palm industries. They have physiological characteristics of their fruit pigmentation, content and height. These cultivars are; Dura, Pisifera, Tenera and Date palm (Tissue culture). Tissue culture or clones of oil palm in 1970s was reported by (Rabechault and Martin, 1976) and its success hybrid was marked with high resistance to *Ganoderma*, *Fusarium* and blast diseases according to Purand-Gasselin *et al.*, (1999). It also had lower in height and good oil and bunch characteristic according to Rohani *et al.*, (2000). It is highly uneconomical to harvest extreme tall oil palm trees.

According to Latiff, (2000) Dura, Pisifera, Tenera are distinguished based on the endocarp, shell thickness and mesocarp content of their fresh fruit bunches (FFB).

Pisifera palms are not planted at commercial scale, due to the fact that they are female sterile cultivar and better cross breed with Dura to form Tenera (D×P). Dura palms have been used for genetic improvement programmes with highest palm kernel content of (7-20%) fruit weight (Stephen and Emmanuel, 2009), a medium mesocarp content (35%-55%) and 2-8mm thick endocarp (Latiff, 2000), but with very low oil extraction ratio (OER) of 12-16%. Pisifera cultivar palms usually have approximately 95% mesocarp content with no endocarp while Tenera (D×P) has small kernel of (3-15%) fruit weight (Stephen and Emmanuel, 2009), and is

high yielding hybrid with high mesocarp content of 60%-95% and 0.5-3mm thick endocarp (Latiff, 2000) and has OER of over 25%.

According to Basri *et al.*, (2003) vegetative characters in terms of reduced rates of trunk extension and long bunch stalks are vital to allow for easy harvesting in compacted oil palm plantation with higher planting densities of about 180 palms/ha. However, the planting space of 9×9 m triangle is commonly used in Nigerian Institute for Oil Palm Research (NIFOR) to avoid compaction of oil palm and nutrient competition. A commercial spacing of 130-150 palms/ha is allowed but, 143 palms/ha is most recommendable for an efficient utilization of solar energies as the rows of oil palms are basically oriented north-south direction. Conventional planting depth of 40 cm and 30cm wide is recommendable after 12-15 months nursery period.

In South and Central America there are *Elaeis oleifera*, species which are indigenous to this region, and can easily hybridize with *Elaeis guineensis*. According to Rajanaidu and Jalani (1994c) these american species are notable for their desirable physiological traits including slow height increment, high unsaturation (high iodine value) and resistance to fungus disease known as *Fusarium* wilt.

1.2 Global palm oil production

According to Omuta and Onorkahrage, (1997) Nigeria had the largest export of palm oil in the world in the beginning of 20th century. Up till 1956 Nigeria was markedly known as one of the foremost nation in global palm oil export. Then its national export was raised by 90%, due to financial returns from production of more than 40% total world's kernel export and 20% palm oil at the international market.

But, unfortunately, according to Omuta and Onorkahrage, (1997) between 1929 and 1974, there was a drastic fall in palm oil production in Nigeria and its total export decreased from 47 - 13.2%. In 1987 Nigeria's palm oil production amounted to approximately 0.65 million tonnes, earning her the third position in global palm oil production (see fig1).

According to Ataga *et al* (1993) the enormous expansion of oil palm growth in Malaysia marked in 1934 surpassing Nigeria, was an aftermath of the British administrators' export of Nigeria oil palm seedlings in 1870s. After the export of palm kernel started in 1832 and by

1911 the British exported 157,000 tonnes of palm kernel and 75 % of this exported palm kernel was relatively from Nigeria.

In Malaysia crude palm oil (CPO) are normally processed by physical (steam refining) and chemical refining processes to produce varieties of products such as refined, bleached and deodorized palm oil (RBDPO) or neutralized, bleached and deodorized palm oil (NBDPO) according to Malaysia Palm Oil Board.

The major growers of oil palm producers in the South East Asia are Malaysia, Indonesia, Thailand, and Papua New Guinea accounting for 90% of world's Palm oil in 2001. According to Basri *et al.*, (2003) Malaysia and Indonesia provide 83% of the world's commercial palm oil produce in 2001, with Malaysia contributing largely 61.1%.

According to Whitmore, (1973) oil palm was introduced as ornamental plant in Malaysia far back in 1875. But, according to Jaqoc, (1952) the first commercial plantation was established in 1917 at Tennamaran Estate in Kuala Selangor. Malaysia has been notable over the years as a leading nation in oil palm production from fresh fruit bunches (FFB), followed by Indonesia and Nigeria (Table 1).

In 2001, the second most important vegetable oil, sourced after soy oil at the international market, was palm oil. But, palm oil is now ranked as the first most important vegetable oil since 2005 amongst other vegetable oils such as rapeseed and soy oil due to the overwhelming cultivation of improved hybrids of oil palm. However, from records the world's production of palm oil was 23.18 million tonnes produced at world's level in 2001 (Table 1). According to FAO (2011) "Palm oil production has more than doubled in the last decade, now dominating the global market for vegetable oil".

On the account of world's export of palm oil, Malaysia contributed with 10.62 million tonnes of the total exports of 17.37 million tonnes in 2001, equals to 61% (Table 2), and was the largest producer of palm oil, account for 11.80 million tonnes or 50.9% of total production, while Indonesia produced nearly 7.5 million tonnes or 32.3% and Nigeria accounted for 0.750 million tonnes or 3.24 % of the total production in 2001 according to Malaysia Palm Oil Board. The largest importer of palm oil is India that accounting for 20.2% of the world's imports in 2001. China and India accounts for 40% of the world's imports of palm oil as major importers

while European Union countries were accountable for buying 17.2% of the world's imports in 2001 according to Malaysia Palm Oil Board.

The import of palm oil by non-European OECD countries was insignificant compared to the rest of other importers as USA imports was approximately 1% and Japan used only 2.2% of total imports of palm oil in 2001 probably due to low consumption requirement according to the Malaysia Palm Oil Board.

Table 1. World production of palm oil (million tonnes)

Country	1990	1995	1999	2000	2001
Malaysia	6.095	7.811	10.554	10.800	11.804
Indonesia	2.413	4.480	6.250	6.900	7.480
Nigeria	0.580	0.660	0.720	0.740	0.750
Colombia	0.226	0.387	0.500	0.516	0.547
Cote d'Ivoire	0.270	0.285	0.282	0.290	0.275
Thailand	0.232	0.354	0.475	0.510	0.535
Ecuador	0.120	0.180	0.230	0.215	0.240
Papua New Guinea	0.145	0.223	0.260	0.281	0.325
Others	0.786	1.097	1.339	1.699	1.226
Total	10.867	15.477	20.610	21.951	23.182

Source: Oil World and MPOB (cited in www.mpob.gov.my)

According to SarVision (2011) "Indonesia overtook Malaysia as the largest producer in 2006, but expansion continues in Malaysia, including deforestation of peatlands".

Moreover, Malaysia palm oil production was according to "Palm Oil-The Sustainable Oil World Growth" September 2009, 17.7 million tonnes in 2008, produced on 4.5mha of land, and still maintained its position as the second largest producer of palm oil, employing more than 570,000 people.

Table 2. World major exporter of palm oil (million tonnes)

Country	1990	1995	1999	2000	2001
Malaysia	5.727	5.613	8.914	9.056	10.618
Indonesia	1.163	1.856	3.319	4.140	4.800

Papua New Guinea	0.143	0.220	0.254	0.282	0.320
Cote d'Ivoire	0.156	0.120	0.105	0.110	0.124
Singapore	0.679	0.399	0.292	0.293	0.259
Hong Kong	0.051	0.275	0.094	0.132	0.187
Others	0.276	0.790	0.837	0.909	1.063
Total	8.195	10.173	13.815	14.922	17.371

Source: Oil World and MPOB (cited in www.mpob.gov.my)

Table3. Major importers of palm oil (million tonnes)

Country	1990	1995	1999	2000	2001
China	1.133	1.595	1.373	1.764	2.049
EU	1.556	1.738	2.059	2.414	2.985
Pakistan	0.683	1.122	1.114	1.107	1.229
Egypt	NA	0.353	0.373	0.524	0.564
India	0.668	0.863	1.672	3.677	3.507
Japan	0.276	0.351	0.357	0.373	0.376
Malaysia	NA	0.038	0.086	0.057	0.116
Turkey	0.182	0.201	0.166	0.204	0.257
South Korea	0.217	0.156	0.151	0.200	0.220
Myanmar	0.134	0.305	0.249	0.202	0.227
USA	0.130	0.102	0.116	0.165	0.171
Bangladesh	0.082	0.053	0.093	0.226	0.320
Indonesia	0.027	0.055	0.025	0.007	0.007
South Africa	NA	0.128	0.160	0.195	0.290
Saudi Arabia	0.128	0.169	0.178	0.206	0.244
Kenya	0.158	0.177	0.178	0.213	0.218
Ex-USSR	0.202	0.057	0.068	0.142	0.202
Others	3.052	2.882	2.451	3.576	4.386
Total	8.628	10.345	10.869	15.252	17.368

Source: Oil World and MPOB (cited in www.mpob.gov.my)

Thus, apart from improvement in crop culture, vegetative physiology of crops, productivity and management all of being characteristic measures for a sustainable production of palm oil food

products and non-food products, also the land area used for world's oil palm commercial plantation has increased in the world (Table 4).

Table 4. World areas of oil palm plantation, 1000ha

Countries	1980	1990	2000	Annual growth rate (%) 1990-2000*
Indonesia	230	617	2014	12.6
Thailand	15	94	199	7.8
Malaysia	805	1746	2941	5.5
Colombia	27	81	134	5.5
Ivory Coast	100	128	139	0.8
Nigeria	220	270	360	2.9
Others	151	527	731	3.3
Total	1756	3463	6563	6.6

Source: Yusof and Chan, 2003

1.3 Potential oil palm yield

According to Breure (2003) in the 80s, 90s and 20s there has been intensive research and developmental priorities to narrow the gap between the commercial yield and the speculations of yield potential for oil palm around 10-11 tonnes/ha/year. In commercial plantations, there are now materials which are capable of producing an oil yield of 7.7 tonnes oil/ha/year from series PS1 in the Palm Oil Research Institute Malaysia (PORIM), compared to the normal 5-6 tonnes/ha/year for PS2. The PS1 series which is a high yielding dwarf palm has a height increment which is only 40cm/year compared to the height increment of 45-75cm/year for PS2.

Other PS planting materials including PS3 and PS4 were reported by (Kushairi *et al.*, 2000) to have been developed after intense selection from the Nigerian germplasm material. These planting materials have been distributed to the oil palm industry for parallel research for industrial large scale breeding.

However, despite improvements in crop culture the production per ha has decreased in Nigeria since 1980. Based on data presented in table 4 and fig. 1 the mean production was calculated to

2.36 ton/ha 1980, 2.22 ton/ha 1990 and 2.03 ton/ha 2000. Thus a loss of around 15% rate of production in just 20 years. There might be several reasons to this, e.g. depletion of soils, less fertile soils being used for new plantations or management mistakes. Depletion of soils may be a result from conversion of forest land to plantation, i.e. increased removal of nutrients with harvest, increased soil erosion and increased soil compaction. It can also be noted that the production per ha is lower in Nigeria than e.g. Malaysia with almost 4ton/ha (Table 1 and 4). This might reflect different site conditions.

According to Ayodele and Thompson (2010) “As of 2011, Nigeria was the third-largest producer, with more than 2.5 million hectares (6.2×10^6 acres) under cultivation”. But by 2012 Nigeria had lost its enviable position in world oil palm production to become fifth world palm oil producer (see fig2).

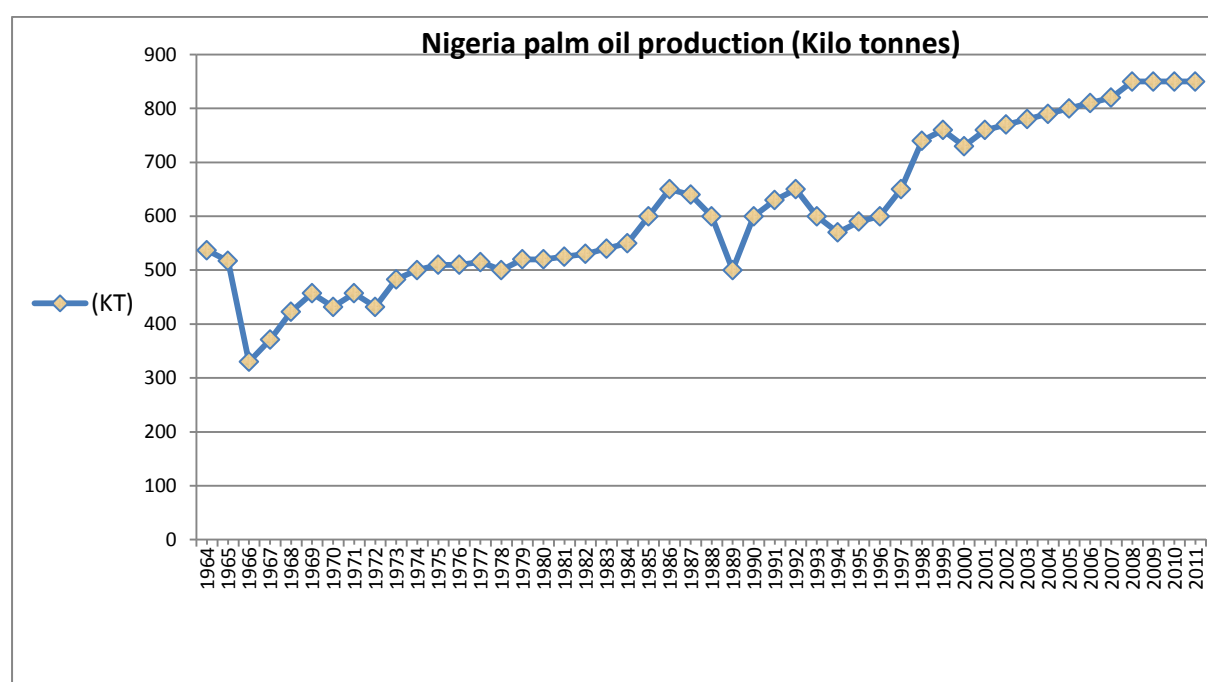


Fig1. Changes in palm oil production in Nigeria from 1964 to 2011, Source: United States Department of Agriculture 2011 (Cited in www.indexmundi.com)

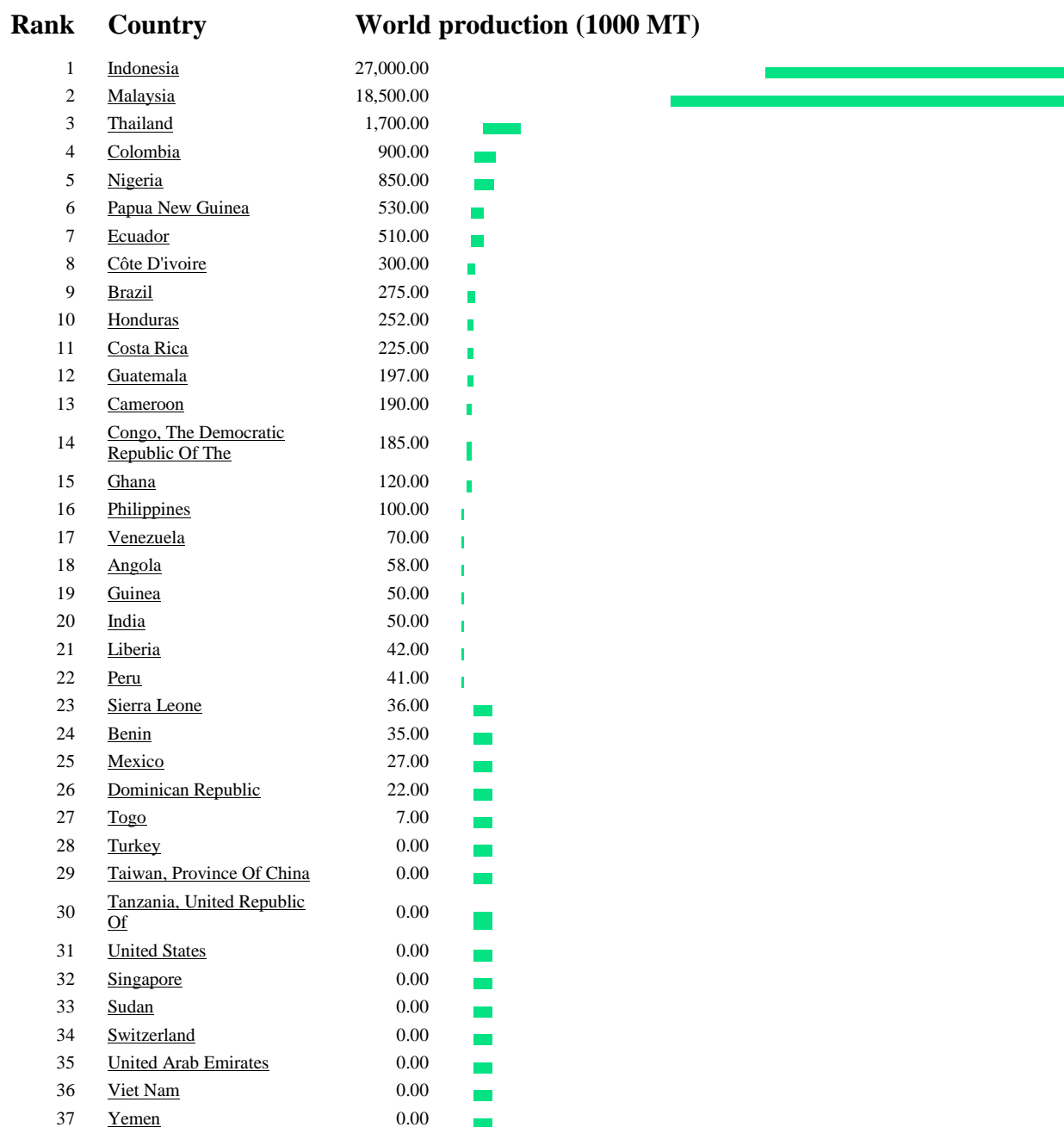


Fig2. Country rankings for world palm oil production in 2012

Source: *www.indexmundi.com*

1.4 The nutritional value and use of oil palm

Palm oil serves for food and non-food purposes as an important source of vegetable fat and oil for an increasing number of humans around the globe. Crude palm oil (CPO) consists to nearly 50% of saturated (mainly palmitic acid) and 50% unsaturated (mainly oleic acid) fatty acids.

Saturated fats are widely regarded as non-desirable food nutrition for humans due to its chemical components of high cholesterol levels and health related diseases such as heart disease. However, some recent studies have suggested that intake of palm oil raises the levels of high density lipoprotein (HDL, 'good' cholesterol) at the expense of the low-density lipoprotein (LDL, 'bad' cholesterol). According to Wahle and James, (1993) it may therefore be safe to accept the dietary component as healthy diet, having favourable balance of saturated and unsaturated fatty acid content. Other reasons to use palm oil as food are the content of vitamins such as A (carotenoid) and E according to Basiri *et al.*, (2003), a free radical scavenger and killer of cancerous diseases.

Most recent studies also show that palm oil consists of a relatively high amount of phenolic antioxidants. Hence with these benefits palm oil is now accepted universally as a healthy dietary food component. In addition the palm kernel seeds are processed to serve as food cakes to livestock. Crude palm oil and palm kernel oil are adaptable vegetable oils of oil palm fruits; nuts, trunk, empty bunch, fibre and sludge now have a wide range of market values in the food and oleochemical industries as illustrated in figure 3.

POME solids are used for animal protein and for generation of biogas to drive electrical devices. From being considered as a waste with harmful environmental impact, the benefits of this reuse are now considered to bring about more value-addition strategies and zero- waste strategies of oil palm mill effluents.

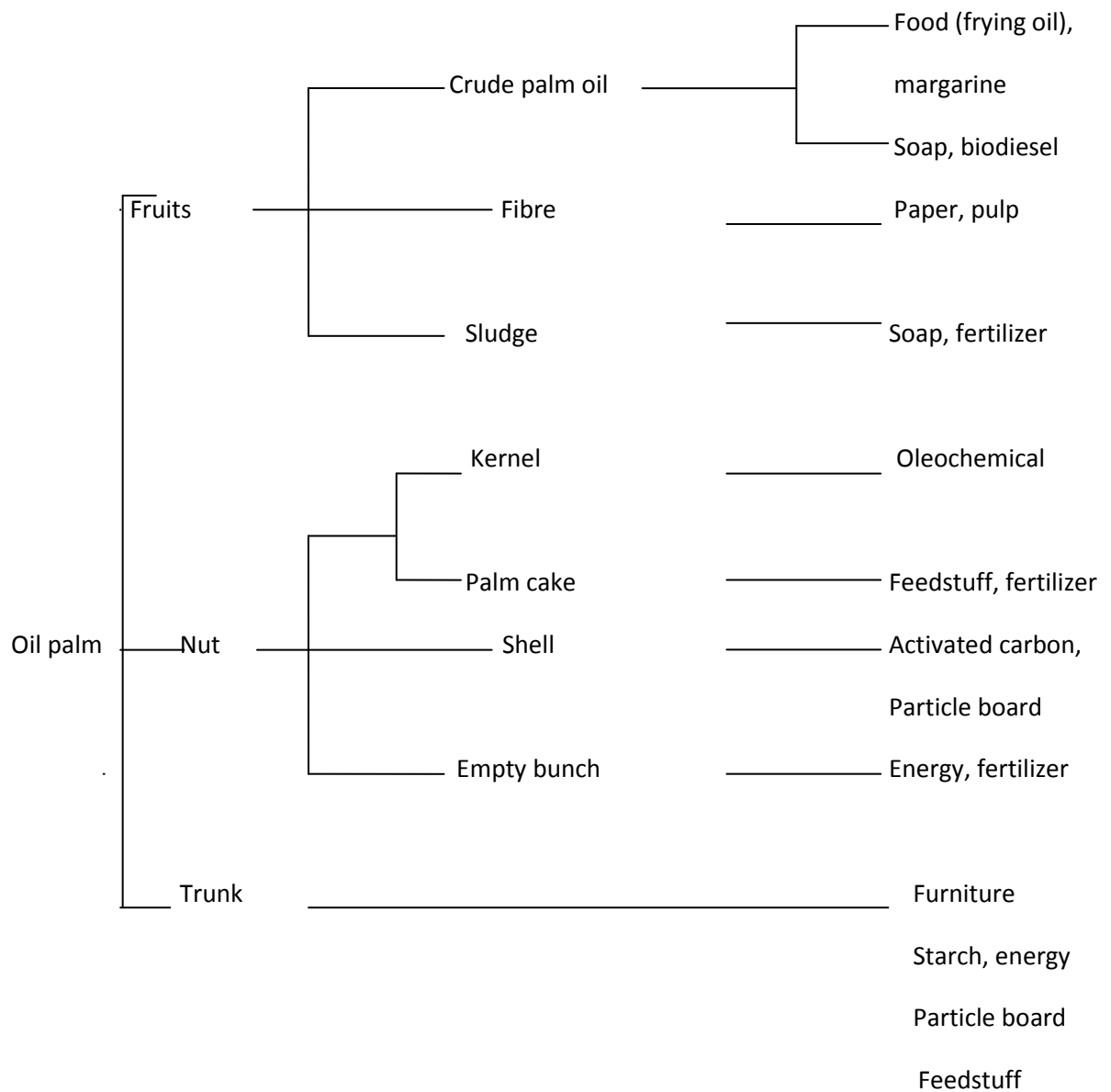


Fig 3. Uses of oil palm biomass in food and manufacturing industries.

Source: Fairhurst and Mutert 1999

1.5 Sustainable and agronomic management practice

Sustainable cropping systems include measures such as; adoption of intensive pest management control, recommended application rate of inorganic fertilizers, little or no tillage mechanism, introduction of the pollinating weevil *Elaeidobius kamerunicus* (Fairhurst and Mutert, 1999); reuse of immobilized nutrients of palm biomass after harvesting, reuse of palm oil mill effluents (POME) and optimum pruning of the 2-3m palm oil petioles (POP) or leaf stalks to create access to fresh fruit bunch (FFB) during harvesting.

Oil palm is a research friendly monoecious flowering plant; hence the association of parasitoids beneficial plants, such as *Cassia cobanensis* and *Euphorbia heterophylla*, as sources of nectar had been widely adopted for oil palm plantations maintenance and in creating a balanced ecosystem for oil palm by potential insect pest control of bagworm and nettle caterpillar according to Basri and Norman, (2000).

1.6 Suitable site conditions for oil palm

A mean minimum temperature of 20-23°C in tropical countries is optimal for oil palm growth and development. Below 19°C, especially at night hours, bunch development and yield rate will be reduced due to lack of sun-shine. The shoot growth of young seedlings stops when temperatures are below 15°C. Thus a mean maximum temperature of 28-33 °C and a constant light of at least 5-7hours per day and at least 1500hours annually are favorable for oil palm growth and development. In addition a mean annual rainfall of 2000mm, (Bunker, 1995) and high relative humidity that exceeds 75 % (Surre and Ziller, 1963) are needed. According to (Smith, 1989; Henson, 1991a) low humidity not only restricts stomata opening, but also the uptake of CO₂ in plants.

Essentially primary macronutrient, which are required in large amount such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) according to Chew and Kee *et al.*, (1994) are basically needed as plant nutrition or fertilizer along with micronutrient such as boron (B), Copper (Cu), Zinc (Zn) etc. According to Tan, (1977) only a good knowledge of nutrient requirement at various vegetative stages will allow for better management options and due recommendations of nutrient supply and rate of application methods are required to achieve greater economic values.

Table 5. Environmental land use conditions and suitability potentials for oil palm growth

Land Characteristic	Highly suitable (S1)	Moderately Suitable (S2)	Marginally suitable (S3)	Not Suitable (N)
Slope % of landscape	0-5	5-8	8-15	>15
Soil erosion hazard	Very slightly	slight	moderate	severe
Soil drainage	Moderately and well-drained soil	Imperfectly drained soil	Poorly drained soil	Very poorly
Amount of concretion and gravels	Non to very few amount	Few	Many	Very many
Effective soil depth(cm)	>120	80-120	60-80	<60
Top soil texture	Loamy, sandy loam, silty loam soils	Sandy clay loam soils	Sandy clay, silty clay, loamy sand soils	
Subsoil texture	Sandy clay loam, clay loam, silty clay loam soils	Clay, sandy loam soils	Loamy sand, heavy clay soils	

Source: Asiamah and Senayah, 1991.

Table 6. Environmental conditions in Nigeria with optimum requirements for oil palm growth

Factors	Optimum requirements by Surre and Ziller, 1963	The Southern Nigeria, (NIFOR)
Amount of rainfall (mm)	1 800-2 200	2 036,5
Relative humidity %	> 75	> 75 June to October
Length of dry season in months during the year	≤3	4-5
Temperature daily max. °C and daily min. °C	25.0–28.0 18.0	30.8-32.2 20.3-22.5
Amount of bright sunshine h/yr.	> 1500	2000
Soil (i) depth (ii) texture (iii) K content (iv) Mg/K and Ca/K	Not less than 1 m 25-30% clay; < 10% clay is unsuitable 0.15-0.20 meq/100g > 2	Seldom less than 1 m Most surface horizons are with < 10% clay content >0.01 meq/100g >1.07 and extremely high
Moisture balance	Q + R>E	Q + R<E during dry season
Distance from the surface to water table	Not more than 3 m	More than 3 m
Water logging	No standing water	No standing water

Q = soil moisture reserve, R = rainfall, E = evapotranspiration

Table7. Soil fertility evaluations for oil palm

Soil property	Very low	Low	Moderate	High	Very high
pH	<3.5	4.0	4.2	5.5	>5.5
Org. C, %	<0.8	1.2	1.5	2.5	>2.5
Total N, %	<0.08	0.12	0.15	0.25	>0.25
Total P, mg/kg	<120	200	250	400	>400
Avail, P mg/kg	<8	15	20	25	>25
Exch.K, meq/100g	<0.08	0.20	0.25	0.30	>0.30
Exch.Mg, meq/100g	<0.08	0.20	0.25	0.30	>0.30
ECEC, meq/100g	<6	12	15	18	>18
Deficiency	likely	Possible	-	-	induced
Fertilizer response	definite	likely	Possible	-	possible

Source: Goh Kah Joo, 1997.

According to Marschner, (1986), tropical acidic soils with (80 to 90 percent sand), available phosphorus, (Bray II) <6 mg/kg; exchangeable calcium, magnesium and potassium, <1.0, <0.4

and <0.2 meq/100g soil respectively are considered to have low levels of available plant nutrients to sustain oil palm growth. According to Rankine and Fairhurst (1999) the response to phosphorus fertilizer is likely to occur when the amount of available phosphorus in the soil is less than 15 mg/kg (Bray II method) during vegetative growth stage of oil palm. In addition an, amount of <4meq Mg/100g was considered too low by Marschner, (1986) but interpreted as very high by Goh Kah Joo, (1997). However, Goh Kah Joo's, (1997) interpretation of the level of Mg was accepted due to findings from this study.

According to Rankine and Fairhurst (1999) to prevent the deficiency of Mg in soils the Ca: Mg ratio should be checked to avoid possible nutrient imbalances which are likely when the Ca: Mg ratio exceeds 5:1 (e.g., volcanic soils).

Table 8. The nutrients requirement rating for oil palm cultivation in NIFOR

Organic carbon	1 - 5%
Organic Matter	3 -15%
Total nitrogen	0.1 - 0.4%
Calcium	2.00 – 10.00 meq/100g soil
Magnesium	0.30- 0.50 meq/100g soil
Sodium	0.10 - 0.40 meq/100g soil
Potassium	0.15 – 2.00 meq/100g soil
pH	5.60 - 6.00
Available phosphorus	8.00 – 20 mg/kg
ECEC	10.00 – 20.00 meq/100g soil
C/N ratio	10 – 20
Boron	6 – 20 mg/kg
Base saturation %	>60, but 50% critical level (Landon, 1984).
Critical level exchangeable sodium percentage (ESP): 10 – 15%, in contrast to sandy soil ESP <25% is considered low and (ESP>5 in clayey soil is considered high).	

1.7 Symptoms of general deficiency in oil palm

There are many different symptoms on nutrient deficiencies in oil palm. Some of them are listed in table 9.

Table 9. Nutrient deficiency symptom in oil palm leaflets

Elements	Distinct symptoms
N	Clorosis
K	Orange spotting/orange blotch
Mg	Orange frond
Cu	Mid-crown chlorosis
B	Hook leaf/crinkel leaf, white strip(due to High N, and Low K)
Zn	Yellow, shortened narrow pinnae

Source: Turner and Gillbanks, 1974.

1.8 Boron

Boron is a major micronutrient element, which is required in relatively high amounts for oil palm in order to sustain its growth and development. According to Alloway, (2008) its deficiency problem is the second most widespread global issue amongst other micronutrients deficiencies.

According to Hartman *et al.*, (1993) commercialization of oil palm plantations is greatly encouraged in the equatorial tropics in South East Asia and South America in various cultivars, Oil palms are mainly grown on highly weathered Oxisol and Ultisols that are derived from granite, sandstones and shale sediments. According to Shorrocks, (1997) these soil types are basically low in boron content as well.

According to Shorrocks, (1997) soil types with widespread boron deficiency are “Ultisol, Lithic Inceptisol, Lithic Fluvent, Alfisol, Psammnet, Oxisol, Spodosol and Andept”. However, alluvial clayey soil is the best soil for oil palm cultivation. In Nigeria, soils that are derived chiefly from basic rocks (basalt and amphiboles) were noted by Cottenie *et al*; (1981) to have higher micronutrients level than soils derived from granite and sandstone. Thus, according to Banjoko *et al*; 1981, parent material was considered as the determining factor of both total and available (hot-water-soluble) boron in Nigeria soils.

Micronutrients are always been removed during each cropping season and harvest time and never replaced to meet nutrient plant uptake demand. According to Okoye, (1980) significant responses to boron application were reported in oil palm grown in southern Nigeria.

According to (Reisenauer *et al.*, 1973; Mortvedt and Woodruff, 1993) the range of toxic level to sufficient level of boron is very narrow compared to other nutrient elements in most plants, hence possible occurrences of excessive and deficient levels might be witnessed seasonally on the growing field.

According to Benton, (2003) boron deficiency results in malformed growth of young palms; and abnormal or retarded elongation of apical (roots-shoots). The youngest leaves are affected first; they will be thick, brittle and small. Due to its slow mobility from older to younger leaves, older leaves usually remain green and appear healthy. According to Rajaratnam (1973) “showed that severe boron deficiency symptoms were related to significantly lower yields” in palms.

However, Ataga *et al.*, (1981) reported that boron and zinc did increase the bunch yield of oil palm cultivated in Ahira soil series in NIFOR, Typic Dystropepts, although the effect was not statistically significant. Similarly, (Udo *et al.*, 1979a; Okpidi, 1984) reported the positive effects of boron in oil palm production on coarse textured acid sand and suggested that an investigation should be carried out on basement complex soils. Hou *et al.*, (1994) noted that “Boron available forms for plant include inorganic borate complexes of Ca, Mg and Na, plus various organic compounds formed from plant remains and microbial decomposition”.

Few or scanty information exist concerning boron level in soils supporting oil palm for over three decades now in Nigeria, hence the need for the present study.

1.8.1 Chemistry of boron in soil

Boron chemistry is very complex as boron is capable of exhibiting unusual bond types in association with hydrogen in aqueous solution. Boron occurs as boric acid (H_3BO_3) in aqueous solution and possibly hydrolyses reversibly to the borate ion $\text{B}(\text{OH})_4^-$ (Goldberg, 1997).



Table 10. Characteristic of boron in aqueous solution

Ionic charge	Approx. bond % to oxygen	Ionic radius	Electronegativity on Pauling scale
3^+	50%	0.023nm	2.0

Source: Goldberg, 1997.

According to Bloesch *et al.*, (1987), boron adsorption on iron oxides are described by four species include: $\text{B}(\text{OH})_4^-$, $\text{B}_3\text{O}_3(\text{OH})_4^-$ and $\text{B}_4\text{O}_5(\text{OH})_4^{2-}$ and $\text{B}_5\text{O}_6(\text{OH})_4^-$. According to Keren and Bingham, (1985) plant available boron source in soils is the neutral boric acid form (H_3BO_3), but, above pH 9.2 the species $\text{B}(\text{OH})_4^-$ becomes predominant and it is non-available for plant nutrient uptake as it is an insoluble species.

1.8.2 Sources of boron

Table 11. Commercial Sources of boron

Refined boron product	Crushed boron ore
Sodium pentaborate, ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 5\text{H}_2\text{O}$),	Colemanite ($\text{Ca}_2\text{B}_6\text{O}_{11} \cdot 5\text{H}_2\text{O}$),
Borax, ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$),	Ulexite, ($\text{Na}_2\text{O} \cdot 2\text{CaO} \cdot 5\text{B}_2\text{O}_3 \cdot 16\text{H}_2\text{O}$),
Sodium tetraborate ($\text{Na}_2\text{B}_{10}\text{O}_{16} \cdot 10\text{H}_2\text{O}$),	Datolite, ($2\text{CaO} \cdot \text{B}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot \text{H}_2\text{O}$),
Solubor, $\text{Na}_2\text{B}_8\text{O}_{13} \cdot 4\text{H}_2\text{O}$)	Hydroboracite, ($\text{CaO} \cdot \text{MgO} \cdot 3\text{B}_2\text{O}_3 \cdot 6\text{H}_2\text{O}$)
Boric acid (H_3BO_3) and Fertibol	Ascarite ($2\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot \text{H}_2\text{O}$).

Source: Bell and Dell, 2008.

According to Bell and Dell, (2008) sodium borates borax and boric acid are rapidly available for plant uptake since they are very soluble in soils with adequate soil moisture content. In addition fertile fertilizer is also very soluble in soils. Thus, amongst the crushed ores ulexite and colemanite are the only ones used for soil application. The commercial sources of boron are either refined products which are soluble with easy plant uptake process or crushed ore which are less soluble due to its chemical composition and insoluble constituents according to

Bell and Dell, (2008). Hence, according to Shorrocks, (1997), boron can be satisfactorily applied to the soil to enhance boron fertility status for sustainable growth of the crop for a long season.

Table 12. Interpretation of boron in soils, based on Wisconsin test results

Soil texture	Very low mgB/kg	Low mgB/kg	Optimum mgB/kg	High mgB/kg	Excess mgB/kg
Sands, Loamy sands	<0.2	0.3-0.4	0.5-1.0	1.2-2.5	>2.5
Sandy Loams, Silts, Loams, Silt Loams, Clays	<0.3	0.4-0.8	0.9-1.5	1.6-3.0	>3.0
Mucks, peats	<0.5	0.6-1.0	1.1-1.2	2.1-4.0	>4.0

Source: Kelling, 1990

Kelling (1990) pointed out that soil test results are probably not utmost reliable means to sufficiently quantify boron availability in soils as it is difficult to predict how much boron that might have been formally released during the growing period.

However, the Wisconsin soil test (Table 12) is not significantly denoted for quantifying boron requirements in oil palm as it not in comparable amount to include the range level of optimum boron requirement for oil palm growth and development, in view of its physiological germplasm or genetic morphological traits.

2.0 AIM AND OBJECTIVES

Aim

The aim is to evaluate the present fertility status of soils in Nigeria for the production of palm oil and in particular investigate the soil boron status.

Objective

1. Review on site conditions needed for oil palm production
2. Determine and evaluate soil physical-chemical status of two states in Nigeria
3. Determine and evaluate boron content in the soil of the two states in Nigeria
4. Investigate the role of treatment and stand age on soil properties
5. Correlate soil boron content with soil parameters
6. Compare the two states with respect to soil boron and other soil physical-chemical parameters

3.0 MATERIALS AND METHODS

3.1 Study Areas

The field work was carried out in Nigerian Institute of Oil Palm Research (NIFOR) main station in Edo State and NIFOR substation in Akwa Ibom State (fig. 3). The main station covers 1735ha, and the substation in Akwa Ibom State covers 246ha of oil palm plantations according to NIFOR data. Edo State is an inland state in the central southern part of Nigeria commonly known as the heartbeat of the nation. Benin City is its capital. Akwa Ibom state is located in the southeastern part of Nigeria. Its state capital is Uyo.

Edo State has a land area covering over 19,794 km². It lies between 05° 44'N and 07°34'N latitudes 05° 04'E and 06° 43'E longitudes. Akwa Ibom State has a land area of over 6,900 Km². It lies between latitudes 04° 32' and 05° 33'N and longitudes 07° 25' and 08° 25'E.

The topography in Akwa Ibom is mainly gently undulating sand plains. In Edo State the soils were sampled from lowland. The water table in NIFOR main station in Edo State is much lower than the water table in NIFOR substation in Akwa Ibom. The soil moisture content in Edo State is very low compared to Akwa Ibom.

These two states were selected due to their significance for oil palm cultivation. Another reason for selecting the sites in Edo State was the good soil maps provided by the authority of NIFOR. Edo State is made up of 19 local government areas. But, study sites used were situated in Ovia North East Local Government Area- NIFOR which is just one of the various local government areas in Edo State. Akwa Ibom has 31 local government areas. The study sites used were situated in Abak which is just one of the local government areas in Akwa Ibom State.

The soil series sampled in Edo State is classified by the NIFOR authority as Kulfo soil series (Ed1), Ahira soil series (Ed2), and Orlu soil series (Ed3) and that of Akwa Ibom is classified as Akwa1, Akwa2, Akwa3 and Akwa4 Abak (kulfo) soil series.



Fig4. Map of Nigeria showing the NIFOR main station in Edo and substation in Akwa Ibom State; where soil samples were collected

Table 13. Summary of location, parent material and vegetation

Locations in Nigeria	Profile site No	Sample identity	Parent material	Vegetation
Edo State	Ed1	Field 9. N06° 34.213' E005°37.320' Age: Fallow land	Marine deposits	Low land rain forest
	Ed2	Field 10. N06° 34.195' E005°37.387' Age: 41 yrs		
	Ed3	Field 17. N06° 32.276' E005°37.280' Age: 49 yrs		
Akwa Ibom State	Akwa1	Field established 2003, Last fertilized 2008 N04°55.447' E007°47.159' Age: 8 yrs	Marine deposits	Rain forest/fresh water swamps
	Akwa2	Field established 2000 N04°55.754' E007°46.783' Age: 11 yrs		
	Akwa3	Field established over 30 years N04°55.397' E007°46.682'		
	Akwa4	N04°56.445 ' E007°46.32' Age: 60 yrs		

*Akwa 1 is the only field with history of been fertilized with single phosphate and refined rock phosphate.

3.1.1 Climate in Edo State

Edo state falls within the transitional zones in the southern Nigeria and is characterized by two rainfall peaks. The first rainy season period begins around March and lasts to the end of July with a peak rainfall maximum in June (Oyenuga, 1967). This rainy period is immediately followed by a short dry break in the month of August (August break) normally observed as a short dry season lasting between two to three weeks.

Once after this break period in August a short rainy season with peak maximum rainfall in early September starts and continues until Mid October. This rainy season is usually followed by long dry season lasting from late October to early March, with peak dry weather conditions between early December and late February. This kind of seasonal patterns is similar in Akwa Ibom State only that Akwa Ibom differs in higher amount of rainfall compared to all other southern parts of Nigeria.

Table 14. Rainfall distribution (mm) in NIFOR Meteorological Station, in Edo South, Nigeria

Months	2004	2005	2006	2007
January	35.2	Nil	22.5	Nil
February	13.5	15.7	10.5	104.2
March	55.3	167.2	61.1	56.2
April	106.4	114.4	158.0	197.7
May	323.4	138.9	246.8	246.2
June	355.7	292.7	172.5	380.9
July	214.3	406.8	289.0	284.7
August	298.6	80.9	335.9	171.4
September	251.1	177.3	347.4	256.0
October	247.0	167.2	304.5	285.0
November	28.3	33.9	24.7	37.1
December	Nil	Nil	Nil	17.1
Total	1928.8	1595.0	1972.9	2036.5

Rainfall and soil moisture regime in Edo South (NIFOR)

Data records from the NIFOR meteorological station in Edo South were used in assessing the rainfall distribution, temperature and the moisture regimes although there could be some minor deviation in rainfall intensity and duration in Akwa Ibom. The rainfall pattern in Edo State is a bimodal type with the peak in June – July and August – September.

However, the annual total rainfall ranged from 1595.0mm in 2005 to 2036.5mm in 2007 in Edo South, which falls within the general rating requirement for oil palm growth and development. Thus, with the relative occurrence of 4 – 5 months of dry periods accompanied by low soil moisture content had been problematic for nutrients uptake processes. From the data of rainfall distribution and in NIFOR meteorological station, in Edo South, the occasional rainfalls during the dry season are too few and not enough for the evapotranspiration demand of the oil palm grown in Edo South. This could be due to a low relative humidity and a high soil moisture deficit that amount to between 350 and 450mm per year.

Temperature rating in (Edo South) NIFOR

The air temperature in Edo South is determined to a large extent by the rainfall pattern. In the dry season during the months from November to April, the mean maximum air temperature ranged from 30.8°C in 2004 to 32.2°C in 2007 and in the wet season it ranged from 20.3°C in 2004 to 22.5°C in 2007 respectively.

Sunshine in Edo State

Edo State enjoys an average of 5-8 hours sunshine per day and it is essentially distributed throughout the year with a solar radiation estimated to range from 201 and 492cal/cm²/day with lower values in the rainy season and higher values in dry season.

3.1.2 Geology and soil hydrology in Ovia North East Local Government in Edo State

The site is characterized by the Benin rock formation, and soils in general are red laterite soil with some clay patches in most of the landscape around NIFOR station in Ovia North East Local Government in Edo State. The soils have fairly high water retention capacity with topography which is generally consisting of gentle slope (Edema *et al.*, 2002).

The river Okhuo, situated in Ovia North East Local Government Area of Edo State, runs along the north boundary of the Nigerian Institute of Oil Palm Research (NIFOR) has catchments areas which are characterized by fringes of dense populated forest vegetation. This river serves as a major source of water supply route for the NIFOR communities as a whole as most of the staff is resident in this locality. However, Edo State in geological terms is characterized by sedimentary marine deposits, laid during the late tertiary and late cretaceous era (Reyment, 1965) as also seen in the coastal line of South Sahara in Africa.

3.1.3 Geology, soil hydrology and climate condition in Akwa Ibom State

This area in south east Nigeria is underlain by marine deposits of late Tertiary and Holocene age.

Geologically, according to (Short and Stauble, 1967; Murat, 1972) Akwa Ibom State is made up of two Southern Sedimentary Basins which include Niger Delta and the Calabar Flank. The Niger Delta Basin is constituted by three major Basins which include Akata Formation, Agbada Formation and Benin Formation. According to (Petters and Ekweozor, 1982; Ramaanathan and Fayose, 1989) the Southern sedimentary Basin consist of mainly shales, sands, sandstones and clay.

According to Edet, (1993) “The prevalent wet and dry season are marked by fluctuations in the amount of precipitation (230 to 390 mm monthly) rather than by variation of temperature” with a relative annual humidity of only 83%. The terrain is virtually flat to gently undulating sandy plains at Abak, Ikot Ekpene, Ini, Ikono, Itu and Etinan, Ibiono local government areas. According to Esu *et al.*, (1999) this region is drained mainly by the Kwa Ibo and Cross Rivers and tributaries such as Etim Ekpo River. Generally, according to (Esu and Okereke, 2002; Masasan and Quinn-Young, 1977) Akwa Ibom State is characterized by low-lying coastal and deltaic plains.

Akwa Ibom State is noted for its low land rain forest, wetlands, fresh and salt water swamp forest saline mangroves or brackish water. The annual temperature in Akwa Ibom State varies between 26°C-36°C, while its total annual rainfall ranges from 4000mm along the coast to 2000mm inland.

There are soil units such as (Dystric, Mollic and Umbric Fluvisols) horizons. The abundant soil mineral is quartz, and monocrystalline quartz constitutes about two-thirds of the quartz varieties. Generally, with the coarse sand textures in Akwa Ibom State the coast are now weathered into lateritic layers.

3.2 Sampling

At Edo State, soil samples were collected from three sites; one fallow land that had never been cultivated with oil palm and two representative sites cultivated with oil palm of different ages (Table 13). At Akwa Ibom State, soil samples were collected from 4 sites; 8, 11, 30 and 60 years old plantations. The soil in each one of the sites was sampled at depth 0-15cm, 15-30cm, 30-45cm, 45-60cm, 60-75cm, 75-90cm, 90-105cm, 105-120cm. At each site four sample points were taken at each respective soil depth and bulked into a composite sample and replicated. An auger was used to obtain the soil samples which were transferred into well labeled polyethylene bags for easy processing.

3.3 Sample preparation

The soil samples were evenly spread on a well labeled tray for air drying after removal of stones, particles, and debris, charcoal and leaves materials by hand sorting. The soil samples were later crushed in a porcelain mortar and sieved using a 2mm sieve and kept in a well labeled polyethylene bag for laboratory analytical purpose.

3.4 Determination of soil texture

The Bouyoucos, (1951) hydrometer method was employed in the particle-size analysis of the bulked soil samples. 100g of the air dry processed soil sample was transferred into dispersible polyethylene bottles. Then 50ml of 5% sodium hexametaphosphate ($\text{Na}_6(\text{PO}_3)_6$ (calgon solution) was added and immediately followed by addition of 1M NaOH and 200ml deionized water, and bottles were placed in a reciprocating shaker for 3hrs. The content of each dispersible polyethylene bottle were then transferred into Bouyoucos measuring cylinder and made up to a mark of 1130ml with deionized water. The Bouyoucos measuring cylinders were slightly inverted and shaken manually and placed on the bench to equilibrate overnight at room temperature 23°C. The same procedure was followed to obtain a blank, without any soil sample.

The following day the content of the various Bouyoucos measuring cylinder were again made to obtain a uniform suspension by carefully mixing for 30seconds, and a time of 40seconds was recorded by a timer as the thermometer firstly was introduced and read thereafter the hydrometer were carefully inserted and read. The hydrometer reading at 40seconds represents the amount of silt plus clayey particles as the sand particles at this time have settled down. The

raw hydrometer reading (R) of the soil samples in the cylinder were subtracted from the actual blank reading (R_L) to obtain a more accurate density D (in g/L) of the suspended solid particles.

Where $D = R - R_L$

The hydrometer and the thermometer readings were again carried out after 5 hours to determine the amount of clay in the suspension as the silt had settled to the bottom.

Calculation:

$$\% \text{ Clay} = (100/w) (R_{5hrs} - R_L)$$

$$\% \text{ Sand} = 100 - (100/w) (R_{40s} - R_L)$$

$$\% \text{ Silt} = 100 - \% \text{ sand} - \% \text{ clay}$$

Where w is the weight of air dry soil in 1130 mL of the soil suspension.

3.5 General soil chemical analyses

3.5.1 Determination of soil pH

Buffer solutions of pH 4.0, 7.0, and 10, were used to calibrate the pH meter. 20ml of distilled water was added to 20g of processed soil sample in a 50ml beaker container in ratio 1:1 (soil : water ratio, w/v) (Thomas, 1996).and allowed to stand for 30minutes and stirring occasionally with the use of a glass rod. The pH meter readings were taken when the pH meter electrode was inserted in the partly settled mixture.

3.5.2 Determination of organic carbon

The determination of organic carbon was carried out by a modified Walkley Black, (1934) method by means of potassium dichromate back titration (wet oxidation method).

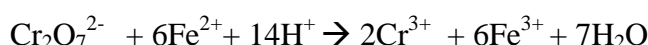
The porcelain mortar and a pestle were used to ground 5g of the processed soil. Thereafter the soil was sieved through a 0.5mm sieve. Subsequently, 0.5g of the homogenized and sieved soil samples were weighed into 250ml Erlenmeyer flasks, and 10ml of 0.4M $K_2Cr_2O_7$ solution was added into the flasks which were swirled gently to mix. Thereafter 20ml of concentrated H_2SO_4 was dispensed a little at a time by using the automatic pipette and mixed thoroughly, as the reaction was exothermic.

The content of the flasks was allowed to stand for 30min on an asbestos sheets, 60ml distilled water was added into the flasks. The content was titrated against 0.5M $(NH_4)_2SO_4.FeSO_4.6H_2O$

(ferrous ammonium sulphate solution) using 6 drops of 1% diphenylamine[(C₆H₅)₂NH] over a white background and at near end point the solution of soil samples was dark blue, followed by drop-wise addition of titrate, the colour sharply changed from dark blue to green. A blank titration was carried out to standardize the K₂Cr₂O₇ in the same way without the processed soil samples.



In the reaction above 2 moles of Cr₂O₇²⁻ oxidize 3 moles of carbon, following the back titration reaction process, while the unreacted excess (unreduced) of the Cr₂O₇²⁻ that remained was titrated against ferrous ammonium sulphate and the organic carbon was calculated.



Calculation:

$$\% \text{Oxidizable organic carbon (w/w)} = [\text{M} (\text{V}_1 - \text{V}_2) \times 0.39] / \text{W}_s$$

M = molar concentration of (NH₄)₂SO₄.FeSO₄.6H₂O solution

V₁ = Volume of (NH₄)₂SO₄.FeSO₄.6H₂O solution required to titrate the blank (ml)

V₂ = Volume of (NH₄)₂SO₄.FeSO₄.6H₂O solution required to titrate the soil sample (ml)

W_s = Weight of air dry soil sample (g)

$$0.39 = 3 \times 10^{-3} \times 100 \times 1.3$$

Where, 3 is the equivalent weight of carbon. This method somewhat provides a recovery of lower organic carbon on assumption of 77% recovery, hence a correction factor of 1.3.

$$\% \text{Total organic carbon (w/w)} = 1.334 \times \% \text{Oxidizable organic carbon}$$

3.5.3 Determination of nitrogen

The determination of nitrogen was made by the macro Kjeldahl, (1983) method. One tablet of selenium catalyst and 4.0 ml of concentrated H₂SO₄ were added to 0.2 g of finely grounded soil in a 100 ml digestion tube. The tubes were subjected to heating on a digestion block until clear solutions were seen. The tubes were allowed to cool for a while after they were removed from the digestion block and 10 ml of distilled water was added into the tubes. The solutions were filtered into 100 ml volumetric flasks using Whatman No. 42 filter paper.

10 ml of distilled water was again added to each of the 100 ml volumetric flasks after filtering of the digestion mixture, followed by addition of 4.5 ml alkaline phenate, and stirring. 3 ml of potassium sodium tartrate was later added along with 2.5 ml sodium hypochlorite. The mixture was stirred and allowed to develop a colour.

The absorbance of all samples prepared, was read at 630 nm, considering a set of standard samples prepared from 25mg/l NH₃ solution. The graph of absorbance against concentration was plotted and the reciprocal slope was calculated.

Calculation:

$$\%N = [A \times SR \times V1 \times V2 \times 100] / W_s \times V3 \times 10^6$$

A = Absorbance

SR = Slope reciprocal

V1 = Volume of extract

V2 = Volume of colour developed

V3 = Aliquot used

W_s = Weight of air dry soil sample (g)

3.5.4 Determination of plant available phosphorus

The plant available phosphorus was determined by the Bray and Kurtz, (1945) method. 5g of the homogenized soil samples were transferred into 150ml plastic bottles. The extracting solution of 35ml 0.03M NH₄F in 0.025M HCL were introduced into the plastic bottles and stoppered. Then a Whatman filter paper No. 42 was used to filter the content of the plastic bottles after manually shaking for 60seconds prior to filtering.

5ml of the filtrate each respectively was pipette into 100ml polyethylene bottle, immediately followed by addition of 4ml (ammonium molybdate [(NH₄)₆Mo₇O₂₄.4H₂O] and ascorbic acid (C₆H₈O₆) reagent) phosphorus developer. The content in each of the 100ml polyethylene bottles was allowed to then stand for 60s. Thereafter instrumental readings were taken at 882nm using the Unico, UV/Visible spectrophotometer. The absorbance of samples and (standards working series, prepared from primary calcium orthophosphate) were read to obtain the slop reciprocal.

Calculation:

$$P \text{ mg/kg} = [A \times SR \times V1 \times V2] / W_s \times V3$$

Where A, SR, V1, V2, W_s and V3 are as previously defined.

3.5.5 Determination of exchangeable base cations

5g of processed air dry soil samples were transferred into 250ml polyethylene bottles with stoppers. The extracting solution of 100ml of neutral NH₄OAc solution of pH 7 was added to each of the polyethylene bottles and the content were shaken for 30minutes. The content of the

various polyethylene bottles were then filtered with Whatman filter paper No. 42. The extracts from the soil samples were then used for the determination of Na, K, Ca, and Mg in meq/100g soil. A blank solution was prepared from 100ml of ammonium acetate (NH_4OAc) solution which was introduced into plastic tube without the soil samples.

The standard working series were prepared from Na_2CO_3 , K_2CO_3 , for Na and K, while CaCO_3 , MgCO_3 for Ca and Mg, and the slope reciprocal was then determined from the plots of absorbance versus concentration.

The standard working solution was measured and the blank solution was used to calibrate the instrument (flame photometer for Na, and K, while the atomic absorption spectrophotometer was used for Ca and Mg) in order for the readings to fall within measurable range. 5 ml of the extracts solutions of the soil samples were introduced into 50ml volumetric flask. 1ml 2.8% lanthanum chloride solution was added to each respective plastic tube and diluted with 1M NH_4OAc extraction solution. Then each of the extract solution in the plastic tubes was aspirated into the flame photometer and atomic absorption spectrophotometer instrument for the various analyses of the base cations.

Calculations:

The unit of meq/100g of soil was used to express the concentration of Na, K, Ca, and Mg in the soil samples as expressed below:

$$[A \times SR \times V_1] / W_s$$

Where A, SR, V_1 , and W_s are as previously defined

$$\text{Cation exchange capacity in meq/100g} = \text{cation} [(\text{mg})/100\text{g}] / E$$

Where A, SR, V_1 and W_s are as previously defined.

Where, E = equivalent of weight of cation $\times 10$

$$\text{Na} = 22.99, \text{K} = 39.10, \text{Ca} = 20.10, \text{Mg} = 12.16.$$

3.5.6 Exchangeable acidity in soil

5g of the air dry soil processed samples were weighed and transferred into 250ml polyethylene bottles. 50ml of 1M KCl was added and then shaken for 60minutes, and then filtered using Whatman No 42 filter paper. The extracted contents were later transferred into 150ml conical flask and then followed by the addition of 2 drops of phenolphthalein indicator. The resultant solutions were then titrated against 0.05M of NaOH to form a permanent pink colour end point.

This first titre gives the exchangeable acidity. And thereafter added 10 mL 1.M NaF (aluminium complexing solution) and titrate with 0.05M HCl until pink color disappears. And waited for 30 min and thereafter added HCl to a clear end point. This titer gives exchangeable Al.

Calculation:

meq/100 KCl acidity = [(mL NaOH sample – mL NaOH blank) × molarity]/sample, g

meq /100 KCl exchangeable Al = [mL HCl × molarity]/sample, g

Where mL = titre value

3.6 Determination of extractable boron

The Azomethine-H Colorimetric (modified Bingham (1982) method was used to determine boron as follows;

Reagents:

1. Azomethine-H
2. Ascorbic acid
3. Ammonium acetate
4. EDTA disodium salt
5. Acetic acid
6. Stock solution of boric acid

Standards stock solution

0.57g of boric acid (H_3BO_3) was dissolved in 1litre of deionized water to obtain a solution of 100ppm of B.

Instrument Calibration Standards

The prepared 100ppm B stock solution was pipeted into 100ml volumetric flask and dilutes to mark with deionized water and mixed thoroughly.

Stock Solution	Final Concentration	Absorbance
ml	ppm	Ibs/A
0	0	0
2	2	0.445
4	4	0.506
6	6	0.664

8	8	0.649
10	10	0.691

Azomethine-H Solution:

1. The amount of 0.9g azomethine-H was weighed into 100ml, volumetric flask containing 50ml of deionized water
2. 2% ascorbic acid was added to the volumetric flask containing the azomethine-H
3. Hot water bath was later used to dissolve the contents in the volumetric flask by heating and allowed to cool.
4. Finally the volumetric flask was made to mark by deionized water and stored for 24hrs

Buffer masking agent

25g of ammonium acetate (NH_4OAC) was dissolved along with 15g EDTA disodium salt using 400ml of deionized water in 1litre beaker container and slowly added 125ml glacial acetic acid.

Extraction solution

115.6g of ammonium acetate was weighed and transferred into beaker container with 800ml deionized water and mixed well. Glacial acetic acid was introduced to adjust the pH to 4.8. The solution was then transferred into a measuring cylinder and made to 1100ml with deionized water.

Extraction procedure

25ml of the extraction solution was used to extract 5g of processed air dry soil sample in an extraction bottles and later left to shake for 5minutes in a reciprocating shaker. Whatman No42 filter paper was used to filter the extract. 2ml of the buffer solution was pipetted into the extract and swirled. Then 2ml of azomethine-H solution was added and left to stand for 30minutes and 1:2 yellow colour complexes was formed. A blank solution was prepared to calibrate the spectrophotometer instrument and the various extract coloured samples were read at 430nm.

Calculation:

$$B \text{ mg/kg} = [A \times SR \times V1 \times V2 \times 100] / W_s \times V3$$

A = Absorbance

SR = Slope reciprocal

V1 = Volume of extract

V2 = Volume of colour developed

V_3 = Aliquot used

W_s = Weight of air dry soil sample (g)

3.7 Electrical conductivity

20ml of deionized water was transferred into a beaker containing 20g of soil, thereafter the electrical conductivity was read with an electrode of the electrical conductivity meter expressed in ($\mu\text{S}/\text{cm}$).

4.0 RESULTS AND DISCUSSION

4.1. NIFOR Main Station in Edo State

4.1.1 Some physicomorphological properties

Soil Units: The studied soils in Edo State were classified as plinthic arenosols (WRB 1998) due the predominant sandy texture and the occurrence of petroplinthic horizons.

Particle size distribution and colour values in the Edo State soil are presented in Table 15. Soil texture varied from silt in the Ed1 to predominantly sand in the Ed2 and Ed3 profile. The Ed1, Ed2, and Ed3 profiles had sandy texture in the surface and in the subsurface layer (Table 15). The low silt (0.70 – 2.90%) and clay (2.05 – 7.30%) contents in Ed1, Ed2 profiles indicated low water-holding capacity, which signified that the soils are not sticky and not plastic when wet and not hard nor cracking on drying. High clay content (14.40 – 23.25%) in the Ed3 sub-subsurface layer indicated it was moderately suitable but not up to the optimum clay requirement of 25- 30% described by Surre and Ziller, (1963) in Table 6, for oil palm cultivation. The low fractions of silt and clay in most profiles probably reflected the parent material composition.

The dominant colours in the soil varied from 10YR to 2.5Y with very dark grayish brown to black (2.5 Y 2/0) colours in the majority of the profiles (see table 15). This implies that the colours of these tropical soils are greatly influenced by the occurrences of iron and manganese.

Table 15. Some physical and morphological characteristics of soils in Edo State (NIFOR main station)

Profile No	depth (cm)	Sand (%)	Silt (%)	Clay (%)	colour values (Munsell)	Texture
	0 - 15	96.55	1.40	2.05	2.5 Y 2/0	S
	15 - 30	95.35	1.50	3.15	2.5Y 3/2	S
	30 - 45	95.50	1.05	3.45	2.5Y 3/2	S
Ed1	45 - 60	94.45	1.05	4.50	10 YR 3/2	SCL
	60 - 75	93.50	1.15	5.35	10 YR 3/2	S
	75 - 90	93.15	1.25	5.60	10 YR 3/2	S
	90 - 105	92.95	0.90	6.15	10 YR 3/2	S
	105 - 120	92.10	0.70	7.20	10 YR 3/2	S
	X±SD	94.19±1.52	1.23±0.26	4.68±1.72		
	0 - 15	95.85	1.55	2.60	2.5 Y 2/0	S
	15 - 30	95.15	1.00	3.85	2.5Y 3/2	S
	30 - 45	95.15	1.10	3.75	2.5Y 3/2	S
Ed2	45 - 60	94.10	1.15	4.75	10 YR 3/2	S
	60 - 75	93.00	1.10	5.90	10 YR 3/2	S
	75 - 90	92.95	1.05	6.00	10 YR 3/2	S
	90 - 105	93.00	0.95	6.05	10 YR 3/2	S
	105 - 120	91.90	0.80	7.30	10 YR 3/2	S
	X±SD	93.89±1.39	1.09±0.22	5.03±1.55		
	0 - 15	93.10	2.90	4.00	2.5 Y 2/0	S
	15 - 30	92.55	2.30	5.15	2.5Y 3/2	S
	30 - 45	90.75	2.20	7.05	2.5Y 3/2	S
Ed3	45 - 60	83.55	2.05	14.40	10 YR 3/2	LS
	60 - 75	81.60	1.80	16.60	10 YR 3/2	LS
	75 - 90	79.45	1.50	19.05	10 YR 3/2	LS
	90 - 105	75.20	1.55	23.25	10 YR 3/2	SCL
	105 - 120	76.50	0.70	22.80	10 YR 3/2	SCL
	X±SD	84.09±7.19	1.88±0.65	14.04±7.77		

Ed1 - Fallow land, Ed2 - 41years old oil palm field, Ed3 - 49years old oil palm field, X - mean, SD - standard deviation, S – sandy soil, LS-loamy sand, SCL-sandy clay loam; Y-yellow, R-red.

4.1.2 Chemical properties

The chemical characteristics of Edo State soils studied are presented in Tables 16, 17, and 18.

Soil pH, electrical conductivity, exchangeable acidity, base cation, effective cation exchange capacity and base saturation in Edo State NIFOR main station soils

The pH value (dry) varied from extreme acidic (4.20) in the Ed2 to moderately acid (5.70) in Ed1 profiles. The upper soil surface layer in the Ed1 and Ed3 were observed to be less acidic compared to the top surface layer in the Ed2 profile (Table 16).

Electrical conductivity (EC) revealed distinct differences among the sampling sites and values tend to decrease with profile depth. The lowest (8.34 μ S/cm) occurred in Ed1 which is purely fallow land and the highest (33.93 μ S/cm) value was found in Ed2 with cultivated oil palm (Table 16). It is possible to consider that the Na content may control the level of EC of the soil, since EC positively and significantly correlated to Na concentration ($r=0.608^*$, $P \leq 0.015$).

Similar observations have been made by Higashi and Shinagawa (1985); however, in their study Na content was higher (7.4 – 29.5meq/100g soil). The low EC values in this study probably resulted from the non-saline nature of the soil, having low exchangeable sodium percentage.

In general the soils studied are relatively sandy hence problems related to dispersed clay, crust or low permeability preventing root penetration and nutrient uptake are not obvious.

The exchangeable acidity was found to be low (0.40 meq/100g) in both Ed1 and Ed3 with highest (0.70meq/100g) values in the Ed2. The high exchangeable acidity is in line with low pH values, thus implying acid soil conditions.

The exchangeable base cations ranged from 0.77meq/100g in the Ed2 to 3.30meq/100g in Ed3. The levels of base cations are in general low, suggesting that the soil was low in available nutrients. In addition, the soils are developed in acid parent material which has been strongly weathered.

Table 16. Some chemical characteristics of soils in Edo State (NIFOR main station)

Profile No	depth (cm)	pH(dry)	EC ($\mu\text{S}/\text{cm}$)	exchangeable acidity (meq/100g)	exchangeable base cation (meq/100g)	ECEC (meq/100g)	Base saturation (%)
Ed1	0 - 15	5.70	18.01	0.40	2.14	2.54	84.25
	15 - 30	5.05	11.02	0.40	1.62	2.02	80.20
	30 - 45	4.60	8.34	0.35	1.65	2.00	82.50
	45 - 60	4.75	11.91	0.30	1.58	1.88	84.04
	60 - 75	5.05	11.22	0.40	1.29	1.69	76.33
	75 - 90	4.75	12.88	0.40	0.97	1.37	70.80
	90 - 105	5.10	11.93	0.35	0.93	1.28	72.66
	105 - 120	4.70	10.31	0.35	0.88	1.23	71.54
	X \pm SD	4.96 \pm 0.35	11.95 \pm 2.80	0.37 \pm 0.04	1.38 \pm 0.44	1.75 \pm 0.45	77.79 \pm 5.67
Ed2	0 - 15	4.30	33.93	0.70	2.43	3.13	77.64
	15 - 30	4.40	25.85	0.45	1.72	2.17	79.26
	30 - 45	4.30	23.00	0.65	1.50	2.15	69.77
	45 - 60	4.65	15.95	0.40	1.31	1.71	76.61
	60 - 75	4.40	14.32	0.35	1.22	1.57	77.71
	75 - 90	4.85	11.00	0.50	1.04	1.54	67.53
	90 - 105	4.20	16.02	0.35	1.02	1.37	74.45
	105 - 120	4.35	14.17	0.45	0.77	1.22	63.11
	X \pm SD	4.43 \pm 0.21	19.28 \pm 7.68	0.48 \pm 0.13	1.38 \pm 0.52	1.86 \pm 0.62	73.26 \pm 5.80
Ed3	0 - 15	5.30	24.00	0.20	3.30	3.50	94.29
	15 - 30	5.05	21.86	0.15	2.88	3.03	95.05
	30 - 45	4.95	18.05	0.35	2.55	2.90	87.93
	45 - 60	4.60	13.72	0.35	2.39	2.74	87.23
	60 - 75	4.60	12.99	0.40	1.83	2.23	82.06
	75 - 90	4.75	12.92	0.35	1.98	2.33	84.98
	90 - 105	4.45	11.45	0.25	1.53	1.78	85.96
	105 - 120	4.30	13.11	0.35	1.05	1.40	75.00
	X \pm SD	4.75 \pm 0.33	16.01 \pm 4.71	0.30 \pm 0.09	2.19 \pm 0.74	2.49 \pm 0.69	86.56 \pm 6.45

Ed1 – Fallow land, Ed2 - 41years old oil palm field, Ed3 - 49years old oil palm field, X - mean, SD - standard deviation, EC– electrical conductivity, ECEC – effective cation exchange capacity.

The effective cation exchange capacity (ECEC) values ranged from 1.22meq/100g to 3.50meq/100

(Table16). These are generally low values that are due to high sand content and low soil organic matter content.

The base saturation ranged from moderate to very high. It varies from 63% in the Ed2 to 95% in Ed3 (Table 16).

Total organic carbon, organic matter, total nitrogen, C/N, available phosphorus, available boron and exchangeable sodium percentage in NIFOR main station soils in Edo State

All profiles had very low amounts of organic C even below the soil surface layer (Table 17), with values varying from 0.06% in Ed3 to 1.05% in the Ed1. An explanation to this could be fast rate of soil organic matter decomposition by macro fauna and micro flora and leaching. Soil organic carbon (SOC) plays an important role and Reeves (1997) noted that “SOC is the most often reported attribute from long-term agricultural studies and is chosen as the most important indicator of soil quality and agronomic sustainability because of its impact on other physical, chemical and biological indicators of soil quality”.

The content of soil organic matter (SOM) was assessed by multiplying the C concentration with a factor 1.729. The low SOM levels of the soils thus followed the distribution pattern of SOC and varied from 0.10% in the Ed3 to 1.82% in the Ed1. Carter and Stewart, (1996) in an extensive study reviewed that SOM can not only reduce bulk density (D_b) and increase water holding capacity, but also effectively increase soil aggregate stability.

Total N levels were very low (0.01 – 0.08%) in the Ed1, (0.01 – 0.06%) in the Ed2, with (0.01 – 0.05%) in the Ed3 profile. The low levels of total N levels in all the sites could be due to moisture distress and noxious weeds causing severe palms competition from weeds (e.g. *Imperata cylindrica*, *Mikania micrantha* and *Chromolaena odorata*). Thus, there would be significant fertilizer response in all the soil sites since they are entirely deficient in Nitrogen.

Nitrogen is a macro nutrient required by oil palm. Corley and Mok, (1972) noted that “nitrogen application increases leaf area, and improves leaf production and the net assimilation rate of oil palms”. Thus, the role of N is very important.

The C/N ratio ranged from 6.00 in the Ed3 to 19.00 in the Ed1. The relatively low CN ratios suggest that the plant availability of N is rather high, though the content is low (due to low soil organic matter content)

Available P levels tend to decrease with depth, in the Ed1, Ed2 and Ed3. In the Ed1 the low values of available P were found to range from 2.65 – 17.50mgP/kg, with a mean of

(7.27mgP/kg). In addition, available P in Ed2 ranged from 2.98 – 12.03mgP/kg, with a mean of (6.31mgP/kg) and Ed3 ranged from 3.99 – 21.44mgP/kg with a mean of (7.80mgP/kg) were also considered low (Table 17), since the mean value of both Ed1, Ed2 and Ed3 were below the critical level of 10mgP Bray P-1 /kg (UNIUYO CONSULT, 2003). The use of phosphate rock (PR) for direct application to supply P is recommendable in these soils. The acid nature of the soil ($\text{pH} < 5$) suggests the occurrences iron (Fe) insoluble P compounds, which makes phosphorus unavailable to plants.

Available B (boron) in all the profiles and levels was found to be below the soil optimum level of 12mgB/kg, and in general the values were as low as 5 or lower (Table 17). This indicates a strong deficiency situation and suggests a significant response to B fertilizers. According to Evans and Spark, (1983) boron availability is favoured by acid soil conditions. However, the studied soils were acid and it likely that the low available content were mainly due to low levels of organic matter.

Exchangeable sodium percentage (ESP) varied from 11.11% in the Ed3 to 17.53% in Ed1. The risk of soil salinity problems was considered very low since; the values were lower than 25% (J.W. van Hoorn and J.G. van Alphen, 2006).

Table 17. Some chemical characteristics of soils in Edo State (NIFOR main station)

Profile No	depth (cm)	Total organic carbon (%)	Organic matter (%)	Total N (%)	C/N	available phosphorus (mg/kg)	available boron (mg/kg)	exchangeable sodium percentage
Ed1	0 - 15	1.05	1.82	0.08	13.13	17.50	1.32	11.68
	15 - 30	0.66	1.14	0.05	13.20	11.87	5.17	14.82
	30 - 45	0.43	0.74	0.03	14.33	7.27	6.81	12.73
	45 - 60	0.44	0.76	0.03	14.67	6.56	3.53	13.92
	60 - 75	0.38	0.66	0.02	19.00	5.07	5.17	15.50
	75 - 90	0.34	0.59	0.02	17.00	4.22	5.04	17.53
	90 - 105	0.28	0.48	0.02	14.00	2.65	5.83	16.13
	105 -120	0.19	0.33	0.01	19.00	3.04	1.97	14.77
	X±SD	0.47±0.27	0.82±0.47	0.03±0.02	15.54±2.45	7.27±5.07	4.36±1.91	14.64±1.86
Ed2	0 - 15	0.93	1.61	0.06	15.50	12.03	8.29	12.35
	15 - 30	0.66	1.14	0.04	16.50	10.48	3.94	16.28
	30 - 45	0.45	0.78	0.03	15.00	7.39	4.02	17.33
	45 - 60	0.33	0.57	0.03	11.00	5.67	2.95	18.32
	60 - 75	0.30	0.52	0.03	10.00	5.00	2.95	16.39
	75 - 90	0.30	0.52	0.02	15.00	3.87	2.99	17.31
	90 - 105	0.25	0.43	0.02	12.50	3.11	0.91	12.75
	105 -120	0.14	0.24	0.01	14.00	2.98	0.002*	15.58
	X±SD	0.42±0.26	0.73±0.45	0.03±0.02	13.69±2.30	6.31±3.39	3.26±2.47	15.79±2.17
Ed3	0 - 15	0.68	1.18	0.05	13.60	21.44	4.68	11.52
	15 - 30	0.55	0.95	0.03	18.33	10.05	0.04	11.46
	30 - 45	0.43	0.74	0.03	14.33	7.45	1.72	13.73
	45 - 60	0.36	0.62	0.02	18.00	6.30	4.43	12.55
	60 - 75	0.30	0.52	0.02	15.00	4.91	5.50	12.57
	75 - 90	0.26	0.45	0.02	13.00	4.01	11.15	13.64
	90 - 105	0.18	0.31	0.01	18.00	4.23	0.49	11.11
	105 -120	0.06	0.10	0.01	6.00	3.99	0.33	12.38
	X±SD	0.35±0.20	0.61±0.33	0.02±0.01	14.53±4.05	7.80±5.90	3.54±3.76	12.37±0.98

Ed1 - Fallow land, Ed2 - 41years old oil palm field, Ed3 - 49years old oil palm field, X - mean, SD - standard deviation, Total N – total nitrogen, C/N – carbon to nitrogen ratio, 0.002* - minimum detectable limit of boron.

Exchangeable bases, Ca/K ratio, Mg/K ratio, Ca/Mg ratio in NIFOR main station soils in Edo State

Exchangeable bases of soils were low in Na, K and Ca and high in Mg (Table 18). Exchangeable Ca ranged (0.45 – 2.20meq/100g), Mg (0.06 – 0.64meq/100g), K (0.02 – 0.08) and Na (0.12 – 0.38meq/100g).

All the three profiles, Ed1, Ed2, Ed3, had exchangeable Ca values which were extremely below 4.0meq/100g regarded as critical level for fertile soils (FAO, 1976; Landon, 1984). According to (Wyn Jones and Lunt, 1967; Burstrom, 1968) reviewed that Ca^{2+} plays an important role in the structural rigidity and function of the cell wall. Low levels in soil can hamper oil palm metabolism.

The soils were well endowed with high Mg (0.63meq/100g 0 – 15cm) in the Ed1, and similar value (0.64meq/100g 0 – 15cm). The exchangeable Mg values exceeded 0.50meq/100g being the critical level for Mg in soils. The levels of distribution of the exchangeable magnesium were high in comparison with the range of 0.02 to 0.24meq/100g soil reported for most well drained soils of southern Nigeria by Thompson and Treoh, (1978). According to Rankine and Fairhurst, (1999)

magnesium functions as the constituent of chlorophyll in plants. Hence, translocation of carbohydrates from leaf to bunch of oil palm is secured when there is incident of sufficient Mg in the soils.

Potassium concentration were very low all the profiles which were less than 0.20meq/100g K, a value described by Unamba-Okpara (1985) as the lower threshold. K concentrations were much lower than that reported for South Africa (1.00 – 2.80 meq/100g soil) (Naido, 1980). According to Rankine and Fairhurst, (1999) potassium has a central role in the osmoregulation of plants (e.g. cell extension and stomata regulation). Hence, it deficiency in soils would reduce bunch size and bunch number of oil palms.

Ca/K ratios in the soil at all sites were very high compared to the optimum requirement >2 described by Surre and Ziller, (1963). Mg/K ratios in the entire sampled sites were high compared to the optimum requirement >2 described by Surre and Ziller, (1963).

Ca/Mg ratios were low averaging 2.76 in Ed2, 4.06 in Ed3 and high in Ed1 averaging 5.09

Table 18. Some chemical characteristics of soils in Edo State (NIFOR main station)

Profile No	depth (cm)	exchangeable calcium (meq/100g)	exchangeable magnesium (meq/100g)	exchangeable potassium (meq/100g)	exchange able sodium (meq/100g)	Ca/K	Mg/K	Ca/Mg
	0 - 15	1.20	0.63	0.06	0.25	20.00	10.42	1.92
	15 - 30	1.03	0.28	0.07	0.24	15.85	4.31	3.68
	30 - 45	1.03	0.34	0.07	0.21	15.77	5.15	3.06
Ed1	45 - 60	1.05	0.26	0.05	0.22	23.22	5.67	4.10
	60 - 75	0.77	0.27	0.05	0.20	17.00	5.89	2.89
	75 - 90	0.62	0.15	0.03	0.17	24.60	6.00	4.10
	90 - 105	0.69	0.06	0.03	0.15	23.00	2.00	11.50
	105-120	0.66	0.07	0.02	0.13	33.00	3.50	9.43
	X±SD	0.88±0.22	0.26±0.18	0.05±0.02	0.20±0.04	21.56±5.79	5.37±2.46	5.09±3.44
	0 - 15	1.29	0.64	0.20	0.30	6.45	3.18	2.03
	15 - 30	0.79	0.50	0.15	0.28	5.27	3.33	1.58
	30 - 45	0.78	0.39	0.07	0.26	11.92	6.00	1.99
Ed2	45 - 60	0.79	0.23	0.05	0.24	15.80	4.50	3.51
	60 - 75	0.67	0.29	0.06	0.20	12.50	4.83	2.31
	75 - 90	0.63	0.18	0.05	0.18	12.50	3.50	3.57
	90 - 105	0.69	0.17	0.03	0.13	23.00	5.50	4.18
	105-120	0.45	0.16	0.04	0.12	11.25	3.88	2.90
	X±SD	0.76±0.24	0.32±0.18	0.08±0.06	0.21±0.07	12.34±5.50	4.34±1.05	2.76±0.92
	0 - 15	2.20	0.64	0.08	0.38	27.44	8.00	3.43
	15 - 30	2.02	0.47	0.06	0.33	36.73	8.55	4.30
	30 - 45	1.66	0.46	0.08	0.35	22.07	6.13	3.60
Ed3	45 - 60	1.69	0.35	0.05	0.30	33.70	7.00	4.81
	60 - 75	1.23	0.33	0.04	0.23	35.14	9.43	3.73
	75 - 90	1.42	0.25	0.04	0.27	35.14	6.13	5.80
	90 - 105	1.05	0.26	0.05	0.17	21.00	5.20	4.04
	105- 120	0.65	0.24	0.03	0.13	26,00	9.40	2.77
	X±SD	1.49±0.51	0.38±0.14	0.05±0.02	0.27±0.09	29.65±6.29	7.48±1.60	4.06±0.93

Ed1 - Fallow land, Ed2 - 41years old oil palm field, Ed3 - 49years old oil palm field, X - mean, SD - standard deviation, Ca/K – calcium to potassium ratio, Mg/K – magnesium to potassium ratio, Ca/Mg – calcium to magnesium ratio

4.2. Abak NIFOR substation in Akwa Ibom State

4.2.1 Some physicomorphological properties

Soil Units: The studied soils in Akwa Ibom State were classified as ferralic arenosols (WRB 1998) due the predominant sandy texture and the occurrence of geric horizons.

Particle size distribution, texture and colour values in Akwa Ibom State soil are presented in (Table 19). Here, soil texture varied from silt in the Akwa4 to predominantly sandy soil in the Akwa1, Akwa2 and Akwa3 profile. The Akwa1 had a mixture of sandy clay loam in the surface and subsurface, loamy sand and sandy clay loam in the sub subsurface. Akwa2 had a mixture of loamy sand in the surface and sandy clay loam in the subsurface horizons. Akwa3 had a mixture of sandy clay loam in the top surface and loamy sand and sandy texture in the subsurface and sandy clay loam in the sub subsurface and Akwa4 having a mixture of sandy clay loam in the top surface, sand and loamy sand in the subsurface and sandy clay loam in the sub subsurface layer.

Low silt (4.35– 12.75%) and clay (2.25 – 12.15%) contents in Akwa2 and Akwa3 profiles indicate moderate water-holding capacity, implying that the soils are not sticky and not plastic when wet and or hard or cracking on drying. Higher clay content in Akwa2 (11.65 – 12.15%) and Akwa3 (10.20 – 11.75%) subsurface layers indicate that these soils are moderately suitable (>10%) but they do not meet the optimum requirement of 25-30% for oil palm cultivation (Surre and Ziller, 1963). It is interesting observation that the clay content in some layers are significantly low compared to that in Edo State soil profiles. It should also be stressed that rainfall regimes is able to compensate for the evapotranspiration requirement of oil palm plantation.

The low fractions of silt and clay in most profiles probably result from their parent material. The dominant colours in the soil varied from 10YR to 2.5Y and 10R with very dark brown to light gray 10YR 7/2 colours indicating reduced iron, reddish brown 7.5YR 5/8 and dusky red 10R 3/3 signifying oxidized iron in majority of the profiles (Table 19). This implies that the soils were being well differentiated into horizons.

Table 19. Some physical characteristics in Akwa Ibom State (Abak NIFOR substation in Akwa Ibom)

Profile No	depth (cm)	Sand (%)	Silt (%)	Clay (%)	colour values (Munsell)	Texture
	0 - 15	86.40	6.10	7.50	2.5Y 3/2	SCL
	15 - 30	86.00	6.55	7.45	10R 3/3	SCL
	30 - 45	85.70	5.55	8.75	10R 3/3	SCL
Akwa1	45 - 60	85.65	5.60	8.75	2.5Y 3/2	SCL
	60 - 75	87.25	5.75	7.00	2.5Y 3/2	SCL
	75 - 90	88.35	5.50	6.15	2.5Y 3/2	LS
	90 - 105	85.10	8.35	6.55	2.5Y 3/2	LS
	105 -120	86.25	6.70	7.05	10YR 7/2	SCL
	X±SD	83.34±1.03	6.26±0.96	7.40±0.94		
	0 - 15	90.25	7.10	2.65	2.5Y 3/2	LS
	15 - 30	89.50	6.25	4.25	2.5Y 3/2	LS
	30 - 45	89.55	6.20	4.25	2.5Y 3/2	LS
Akwa2	45 - 60	86.25	6.70	7.05	7.5YR 5/8	SCL
	60 - 75	83.50	6.80	9.70	10 YR 3/2	SCL
	75 - 90	82.20	6.15	11.65	10R 3/3	SCL
	90 - 105	82.25	5.60	12.15	10YR 7/2	SCL
	105 -120	81.60	12.75	5.65	2.5Y 3/2	LS
	X±SD	86.64±3.70	7.19±2.29	7.17±3.61		
	0 - 15	85.70	5.60	8.70	2.5Y 3/2	SCL
	15 - 30	89.70	8.05	2.25	2.5Y 3/2	LS
	30 - 45	90.60	6.75	2.65	2.5Y 3/2	LS
Akwa3	45 - 60	88.10	6.65	5.25	2.5Y 3/2	S
	60 - 75	86.80	6.55	6.65	10R 3/3	S
	75 - 90	82.55	5.70	11.75	7.5YR 5/8	SCL
	90 - 105	82.75	5.60	11.65	10R 3/3	SCL
	105 -120	85.45	4.35	10.20	10YR 7/2	SCL
	X±SD	86.46±2.95	6.16±1.20	7.39±3.79		
	0 - 15	82.65	5.35	12.00	10 YR 3/2	SCL
	15 - 30	88.65	4.85	6.50	2.5Y 3/2	S
	30 - 45	92.05	5.55	2.40	2.5Y 3/2	LS
Akwa4	45 - 60	91.00	4.90	4.10	2.5Y 3/2	LS
	60 - 75	89.50	4.50	6.00	2.5Y 3/2	S
	75 - 90	90.30	3.30	6.40	10R 3/3	SCL
	90 - 105	89.70	3.30	7.00	7.5YR 5/8	SCL
	105 -120	88.50	3.60	7.90	10YR 7/2	SCL
	X±SD	89.04±2.84	4.42±0.91	6.54±2.81		

Akwa1 – Fertilized 8years old Oil Palm field, Akwa2 – 11years old oil palm field, Akwa3 – 30years old oil palm field, Akwa4 – 60years old oil palm field, X - mean, SD – standard deviation, OMC - organic matter content, S-sand, LS-loamy sand, SCL-sandy clay loam; Y- yellow, R-red.

4.2.2 Chemical properties

The chemical characteristics of Akwa Ibom State soils studied are presented in Tables 20, 21, and 22.

Soil pH, electrical conductivity, exchangeable acidity, aluminium, exchangeable base cation, effective cation exchange capacity and base saturation

The pH (dry) values varied from very strongly acidic (4.45) in the Akwa4 to slightly acidic (6.25) in the Akwa1 profiles. The pH value of 6.25 at depth 30 - 45cm is similar in both Akwa3 and Akwa4. The upper soil layers 0 - 15cm in the Akwa1 (pH 5.30) and Akwa2 (pH 5.25) were found to be strongly acidic compared to slightly acidic (pH 6.15) in the Akwa3 and very strongly acidic pH 4.45 in the Akwa4 soil depth 0 - 15cm (Table 20). However, the soils in Akwa Ibom are neutral when wet and acidic when dry; this acidic tendencies might be due to formation of sulphate from air dry soil samples inherent with FeS (Iron pyrite) in the inter layers of the soils.

Electrical conductivity (EC) revealed distinct differences among the sampling sites and values tended to decrease with profile depths in Akwa1, Akwa2, Akwa3 and Akwa4 except for the extreme low EC at depth 0 – 15cm in Akwa4. The lowest (6.66 μ S/cm) in the Akwa4 and highest (240.00 μ S/cm) values were found in the Akwa2 (Table 19). It is possible to consider that the Na content may control the level of EC of the soil, since EC is positively and significantly but weakly correlated to Na concentration ($r=0.442^{***}$, $P \leq 0.0001$).

Similar observations had been made by Higashi and Shinagawa, (1985); however, in their study Na content was higher (7.4 – 29.5 meq/100g soil). The low EC in the Akwa3 and Akwa4 in this study probably resulted from the likely non saline nature of most of its soil profile with low mean ESP in Akwa3 (10.79%) and Akwa4 (11.07%). However, in the Akwa1 which is a 8years old fertilized oil palm field with mean ESP of 17.60% (Table 21) is considered also low, though its highest ESP ranges from (16.67 – 27.17%) which may have resulted from fertilizing effect on the soil profile and moderate inundation of saline water from nearby swamps. Akwa2 with the highest EC had a mean ESP of only 22.96% which is to be considered to be low for sandy soils according to Van Hoorn and Van Alphen, 2006. Although, in the Akwa2 surface 0 – 15cm, subsurface 15 – 30cm and 30 – 45cm there were indication of slight saline effects on the soil structure. In general the soils can be considered as non-saline in the deeper layers. In

addition, EC is also controlled by H^+ activity, suggesting that the occurrences of low pH values may have resulted to the low EC of all the soil samples.

The exchangeable acidity (EA) levels ranged from moderate to extreme high with values decreasing with depth in the Akwa1, Akwa2 and Akwa4. However, in Akwa3 the values tended to increase with depth. High exchangeable acidity values (0.50 – 1.20meq/100g) and lowest (0.11 – 0.46meq/100g) in the Akwa1, Akwa2, Akwa3 and Akwa4, the area associated with relative large amounts of fibrous roots of red mangrove which had decomposed to produce sulphides responsible for high acidity (Simpson and Pedini, 1985); and release of hydrogen ion in the soils solution by hydrated $Al(H_2O)_5OH^{2-}$, $Al(H_2O)_4(OH)_2^-$ and hydrolysis of Al. Since, the mean values of EA of all the studied oil palm fields were greater than 0.50meq/100g, which is an optimum level. These soils are considered to have a high EA and being susceptible to soil structure deterioration.

The high exchangeable acidity in these soils indicates acid condition which may result from relatively close mangrove swamp forest. Boto and Wellington, 1984, confirmed the observation by Hesse (1961) that plantations exposed to sulphides from neighboring mangrove swamps produce acid soils and therefore subject to reclamation to ameliorate the possible adverse effects of soil acidity.

The exchangeable aluminium (Al) contents of soils followed the distribution pattern of exchangeable acidity, with higher values ranging from (0.45 - 0.50 meq/100g) in Akwa3 and (0.45 - 0.50 meq/100g) in Akwa4 and (0.15 – 0.45meq/100g) in Akwa1, (0.40 – 0.45meq/100g) in the Akwa2 with high variation. Typically, exchangeable Al is dominant at pH values less than 5 (Stumm and Morgan, 1981) and this could be considered as one major sources of exchangeable acidity in the soils. The absolute value of 1meqAl/100g soil can lead to Al toxicity (Amberger, 2006). However, such large concentration of Al was not found in this study, thus most of the soil samples did not indicate the presence of exchangeable Al hence their low pH suggest that the presence of carboxylic and phenolic groups were responsible for the acidic condition of the soils (Swift and Woomer, 1993).

The lowest content of exchangeable base cations was 1.90meq/100g and the highest was 5.60 meq/100g both occurring in the Akwa2 profiles, and ranged from (2.54 – 4.87meq/100g) in Akwa1, (3.31 – 5.30meq/100g) in Akwa3 and (3.10 – 5.19meq/100g) in Akwa4, implying that

the fertility status of soils studied in Akwa Ibom State soils is quite characterized by low amount of plant available nutrients. The exchangeable base cation had high positive correlations with Ca and Mg, thus their availability is influenced by the availability of base cations. In addition Ukpong, (1995) reported much higher values (21 – 45meq/100g soil) of exchangeable base cation while Clarke and Hannan, (1967) obtained much lower levels (0.38 – 0.84meq/100g soil) in Australia mangroves. The differences between them suggest that there may be differences in parent material between the two sites.

The effective cation exchange capacity (ECEC) values ranged from (2.75 – 5.91meq/100) and reflect extremely low exchange conditions in the cultivated rain forest soil on air drying; but much more than the range values in Edo State. Thus, the ECEC were below the recommended 15meq/100g soil required for nutrient and water retaining ability and far below the (Sufficiency threshold) critical values at which nutrient and water can be retained as reported by Henson, (1991). Reasons for low ECEC are the high sand content and the low content of organic matter.

The base saturation ranges from 69.10% in the Akwa2 to 97.45% in the Akwa4. This does not suggest that the soil was actually rich in required amount of cations (nutrients).

Table 20. Some chemical characteristics of soils in Akwa Ibom State (Abak NIFOR substation)

Profile No	depth (cm)	pH(dry)	EC ($\mu\text{S}/\text{cm}$)	exchangeable acidity (meq/100g)	exchangeable aluminium (meq/100g)	exchangeable base cation (meq/100g)	effective cation exchange capacity (meq/100g)	Base saturation (%)
	0 - 15	5.30	34.25	0.65	0.10	4.78	5.43	88.03
	15 - 30	4.85	22.30	1.00	0.15	4.87	5.87	82.96
	30 - 45	4.75	13.76	1.20	0.45	4.27	5.47	78.06
Akwa1	45 - 60	5.10	13.81	0.42	0.07	4.46	4.88	91.39
	60 - 75	5.35	20.20	0.37	0.02	2.54	2.91	87.29
	75 - 90	5.60	32.85	0.23	0.03	4.14	4.37	94.74
	90 - 105	6.00	11.88	0.55	0.00	3.78	4.33	87.30
	105 - 120	6.25	10.77	0.50	0.00	4.52	5.02	90.04
	X \pm SD	5.40 \pm 0.53	19.98 \pm 9.27	0.62 \pm 0.33	0.10 \pm 0.15	4.17 \pm 0.75	4.79 \pm 0.93	87.48 \pm 5.13
	0 - 15	5.25	116.00	0.90	0.20	2.45	3.35	73.13
	15 - 30	5.05	240.05	0.85	0.20	3.31	4.16	79.57
	30 - 45	5.25	150.37	0.85	0.45	1.90	2.75	69.10
Akwa2	45 - 60	5.55	230.65	0.31	0.01	3.45	3.76	91.76
	60 - 75	5.55	120.40	0.46	0.01	3.84	4.30	89.30
	75 - 90	5.70	80.77	0.21	0.01	5.35	5.56	96.22
	90 - 105	5.55	20.60	0.31	0.01	5.60	5.91	94.76
	105 - 120	4.90	23.95	0.82	0.07	3.40	4.22	80.57
	X \pm SD	5.35 \pm 0.28	122.85 \pm 82.96	0.56 \pm 0.29	0.12 \pm 0.16	3,66 \pm 1,28	4,28 \pm 1,06	84,30 \pm 10,17
	0 - 15	6.15	17.11	0.45	0.00	4.82	5.27	91.46
	15 - 30	5.55	14.73	0.30	0.00	5.30	5.60	94.64
	30 - 45	6.25	13.61	0.50	0.00	3.43	3.93	87.28
Akwa3	45 - 60	5.35	12.20	0.30	0.00	3.94	4.24	92.93
	60 - 75	4.60	11.74	0.95	0.50	4.65	5.60	83.04
	75 - 90	4.50	10.90	1.10	0.20	4.54	5.64	80.50
	90 - 105	5.25	21.20	0.80	0.45	3.92	4.72	83.05
	105 - 120	5.25	5.95	0.75	0.45	3.31	4.06	81.53
	X \pm SD	5.34 \pm 0.63	13.43 \pm 4.51	0.64 \pm 0.30	0.20 \pm 0.23	4,24 \pm 0,70	4,88 \pm 0,74	86,80 \pm 5,56
	0 - 15	4.45	6.66	1.10	0.30	3.74	4.84	77.27
	15 - 30	5.20	24.23	0.40	0.00	3.49	3.89	89.70
	30 - 45	5.10	15.56	0.45	0.00	5.19	5.64	92.01
Akwa4	45 - 60	6.25	11.21	0.11	0.00	4.21	4.32	97.45
	60 - 75	6.15	11.71	0.15	0.00	3.10	3.25	95.38
	75 - 90	5.05	13.32	1.05	0.45	3.64	4.69	77.61
	90 - 105	5.50	11.58	1.05	0.50	5.07	6.12	82.83
	105 - 120	5.05	8.32	0.25	0.00	4.22	4.47	94.40
	X \pm SD	5.34 \pm 0.60	12.82 \pm 5.37	0.57 \pm 0.43	0.16 \pm 0.22	4.08 \pm 0.74	4.65 \pm 0.92	88.33 \pm 8.04

Akwa1 – Fertilized 8years old oil palm field, Akwa2 – 11years old oil palm field, Akwa3 – 30years old Oil Palm field, Akwa4 – 60years old oil palm field, X - Mean, SD - standard deviation, EC– electrical conductivity.

Total organic carbon, organic matter, total nitrogen, C/N ratio, available phosphorus, available boron and exchangeable sodium percentage

All profiles suggest very low amounts of organic C particularly below soil surface layer (Table 21), with values varying from 0.07% in Akwa2 to 2.02% in the Akwa1. An explanation to this could be fast rate of soil organic matter decomposition by macro fauna and micro flora or leaching.

The levels of soil organic matter (SOM) in these NIFOR substation sites followed the distribution pattern of SOC and varied from 0.12% in the Akwa2 to 3.47% in the Akwa1. In the Akwa1, the top upper layer had somewhat a margin of higher SOM content but not sufficient to serve as a store house for nutrient availability, just like the rest of the sites

Total N levels were low and vary from 0.01% in the Akwa2 to 0.17% in the Akwa1 soil profile. The low organic C and N levels in the entire soil sites could be due to invasive noxious weeds competition with palms (e.g. *Imperata cylindrica*, *Mikania micrantha* and *Chromolaena odorata*), since these weeds in particular were seen all over the sampled sites. Thus, there would be significant response to nitrogen fertilizer in these soils.

The C/N ratios in all the sampled sites were relatively high with averaged range from 20.35 in the Akwa2 to 18.36 in the Akwa3 except lower values in the Akwa4 with average ratio 12.78 but this suggests that leaching and poor levels of nitrogen were predominant factor in most of the profiles.

The highest concentrations of available P occurred in Akwa1 with values up to 83mgP/kg; however the topsoil was low in available P with only about 5mgP/kg (Table 21). Also Akwa3 displayed a similar picture with generally high concentrations but lower in the uppermost layer, The other sites, Akwa 2 and Akwa4 had much lower concentrations in the subsoil (11-30mgP/kg) but higher in the topsoil (Table 21).

The extremely high available P in Akwa1 could be due to fertilizing. Since, the mean values of the available P in these soils are greater than the critical level of 10mgP Bray P-1 /kg

(UNIUYO CONSULT, 2003); the P status of the soils in Akwa Ibom State was considered sufficient to support the growth of oil palm. The use of phosphate rock (PR) for direct application to supply phosphorus was hereby not recommendable in these soils.

Available boron was considered to be extremely low compared to the mean values of boron in Edo State soils. The mean values of 1.21mgB/kg in the Akwa1, 1.64mgB/kg in the Akwa2, and 2.29mgB/kg in the Akwa3 and 2.20mgB/kg in the Akwa4 were insufficient compared to the optimum soil requirement of 12mgB/kg. Thus, all the oil palm fields are highly deficient in available boron and as such there will be significant response to fertilizer.

However, boron in soils interpreted by Kelling (1990), (Table 12) is not always reliable for assessing the availability to oil palms since the available amount are less dependent on the actual content but more on the mineralization rate.

The reduced levels of available boron content in Akwa Ibom State soils were alarming compared to that of Edo State soils. These lower concentrations could also be due to low levels of organic matter and not the slight traces of salinity.

Exchangeable sodium percentage (ESP) was low (8.29 – 35.79%), far less than 40%, giving as ESP to mean the same value as sodium adsorption ratio (SAR) according to James *et al.*, (1982). However, the role of ESP effects on salinity in principle increases soil available B, but studied result showed that the slight trace of salinity in some layers had no influence on the availability of soil boron.

Table 21. Some chemical characteristics of soil in Akwa Ibom State (Abak NIFOR substation)

Profile No	depth (cm)	Total organic carbon (%)	Organic matter (%)	Total nitrogen (%)	C/N	available phosphorus (mg/kg)	available boron (mg/kg)	exchangeable sodium percentage
	0 - 15	2.02	3.49	0.17	11.88	5.62	0.49	15.69
	15 - 30	1.27	2.20	0.12	10.58	83.51	3.48	14.78
	30 - 45	0.36	0.62	0.02	18.00	71.88	4.68	16.39
Akwa1	45 - 60	0.60	1.04	0.03	20.00	76.93	0.99	16.14
	60 - 75	0.71	1.23	0.05	14.20	71.40	0.002*	27.17
	75 - 90	0.65	1.12	0.05	13.00	75.17	0.002*	17.63
	90 - 105	0.73	1.26	0.05	14.60	67.33	0.002*	16.67
	105 - 120	0.29	0.50	0.02	14.50	75.86	0.002*	16.37
	X±SD	0.83±0.57	1.43±0.98	0.05±0.06	15.52±4.61	69.96±24.84	1.21±1.84	17.60±3.50
	0 - 15	0.78	1.35	0.06	13.00	15.06	2.28	33.88
	15 - 30	0.83	1.44	0.06	13.83	30.32	0.17	25.98
	30 - 45	0.61	1.06	0.04	15.25	26.60	2.63	35.79
Akwa2	45 - 60	0.80	1.38	0.05	16.00	12.14	2.46	19.71
	60 - 75	0.17	0.29	0.01	17.00	11.82	0.33	20.57
	75 - 90	0.30	0.52	0.01	30.00	29.89	4.27	13.46
	90 - 105	0.07	0.12	0.01	7.00	21.12	0.02	12.50
	105 - 120	0.39	0.67	0.02	19.50	12.96	0.99	21.77
	X±SD	0.49±0.30	0.85±0.52	0.03±0.02	20.35±8.15	19.99±8.03	1.64±1.51	22.96±8.54
	0 - 15	0.83	1.44	0.06	13.83	12.23	0.58	10.37
	15 - 30	0.44	0.76	0.02	22.00	12.72	1.65	8.49
	30 - 45	0.39	0.67	0.01	39.00	18.79	5.00	13.41
Akwa3	45 - 60	0.69	1.19	0.05	13.80	28.44	2.88	9.65
	60 - 75	0.72	1.25	0.05	14.40	46.48	1.32	8.82
	75 - 90	0.59	1.02	0.04	14.75	58.63	1.56	11.01
	90 - 105	0.42	0.73	0.02	21.00	59.40	2.79	13.78
	105 - 120	0.42	0.73	0.02	21.00	58.70	2.55	12.09
	X±SD	0.56±0.17	0.97±0.29	0.03±0.02	18.36±5.61	36.92±21.17	2.29±1.35	10.79±2.00
	0 - 15	1.12	1.94	0.10	11.20	36.45	3.65	13.10
	15 - 30	0.49	0.85	0.07	7.00	10.56	2.30	13.75
	30 - 45	0.42	0.73	0.02	21.00	11.35	0.09	9.06
Akwa4	45 - 60	0.82	1.42	0.06	13.67	21.37	2.05	7.13
	60 - 75	0.51	0.88	0.03	17.00	22.72	5.25	15.32
	75 - 90	0.73	1.26	0.05	14.60	15.66	0.002*	11.26
	90 - 105	0.18	0.31	0.02	9.00	16.17	4.19	10.65
	105 - 120	0.76	1.31	0.06	12.67	12.97	0.09	8.29
	X±SD	0.63±0.29	1.09±0.50	0.05±0.03	12.78±3.70	18.40±8.51	2.20±2.04	11.07±2.85

Akwa1 – Fertilized 8years old oil palm field, Akwa2 – 11years old oil palm field, Akwa3 – 30years old Oil Palm field, Akwa4 – 60years old Oil Palm field, X - Mean, SD – standard deviation, C/N – carbon to nitrogen ratio, 0.002* - minimum detectable limit of boron.

Exchangeable bases, Ca/K ratio, Mg/K ratio and Ca/Mg ration in NIFOR substation soils in Akwa Ibom State

Exchangeable bases of soils were low in Ca and high in Mg values being higher than those of Na and K (Table 22). Exchangeable Ca (0.91 – 3.22meq/100g), Mg (0.15 – 2.08meq/100g), K (0.05 – 0.17meq/100g) and Na (0.30 – 0.86meq/100g) values presumably reflect the overall influence of not cutting trees and thereby facilitating the replenishing of the soil from leaf biomass mineralization.

The four profiles, Akwa1, Akwa2, Akwa3 and Akwa4 had exchangeable Ca values which were extremely below 4.0meq/100g regarded as critical level for fertile soils (FAO, 1976; Landon, 1984). The soils were well endowed with high mean values for exchangeable Mg 1.11meq/100g in the Akwa1, 0.80meq/100g in Akwa2, and 1.42meq/100g in the Akwa3 with 0.88meq/100g in the Akwa4. The exchangeable Mg content was greater than 0.50meq/100g being the critical level for Mg in soils. Thus, there were very high levels of magnesium sufficiency in these soils in Akwa Ibom State, (Table 17). These values could be due to the parent material. The exchangeable Mg was in general higher at Akwa Ibom State soils than in Edo State.

Potassium concentration were in general very low all the profiles; less than 0.20meq/100g K a value described by Unamba-Okpara, (1985) as a lower threshold. However at Akwa4 the values exceeded the threshold for some layers (Table 22).

The Ca/K ratios were very high compared to the optimum requirement greater than 2 as described by Surre and Ziller, (1963) (Table 6).

Mg/K ratios in all and sampled sites were with exceptions high compared to the optimum requirement greater than 2 as described by Surre and Ziller, (1963).

Ca/Mg ratios in the sampled sites were low and averaged 3.01 in Akwa1, 4.45 in Akwa2, lowest 1.83 in Akwa3 and the highest mean of 4.75 in Akwa4.

Table 22. Some chemical characteristics of soil in Akwa Ibom State (NIFOR substation)

Profile No	depth (cm)	exchangeable calcium (meq/100g)	exchangeable magnesium (meq/100g)	exchangeable potassium (meq/100g)	exchangeable sodium (meq/100g)	Ca/K	Mg/k	Ca/Mg
	0 - 15	2.77	1.09	0.17	0.75	16.29	6.41	2.54
	15 - 30	2.64	1.38	0.13	0.72	20.31	10.62	1.91
	30 - 45	2.35	1.11	0.11	0.70	21.36	10.09	2.12
Akwa1	45 - 60	2.16	1.44	0.14	0.72	15.43	10.29	1.50
	60 - 75	1.56	0.15	0.14	0.69	11.14	1.07	10.40
	75 - 90	1.88	1.40	0.13	0.73	14.46	10.77	1.34
	90 - 105	2.25	0.78	0.12	0.63	18.75	6.50	2.89
	105 - 120	2.12	1.54	0.12	0.74	17.67	12.83	1.38
	X±SD	2.22±0.38	1.11±0.46	0.13±0.02	0.72±0.04	16.93±3.32	8.57±3.74	3.01±3.04
	0 - 15	1.12	0.35	0.15	0.83	7.47	2.33	3.20
	15 - 30	2.02	0.30	0.13	0.86	15.54	2.31	6.73
	30 - 45	0.91	0.20	0.11	0.68	8.27	1.82	4.55
Akwa2	45 - 60	1.45	1.21	0.11	0.68	13.18	11.00	1.20
	60 - 75	1.77	1.17	0.11	0.79	16.09	10.64	1.51
	75 - 90	3.13	1.41	0.09	0.72	34.78	15.67	2.22
	90 - 105	3.22	1.59	0.09	0.70	35.78	17.67	2.03
	105 - 120	2.40	0.17	0.09	0.74	26.67	1.89	14.12
	X±SD	2.00±0.87	0.80±0.60	0.11±0.02	0.75±0.07	19.72±3.32	21.23±6.64	4.45±4.32
	0 - 15	2.49	1.75	0.08	0.50	31.13	21.88	1.42
	15 - 30	3.14	1.64	0.07	0.45	44.86	23.43	1.92
	30 - 45	1.68	1.23	0.06	0.46	28.00	20.50	1.37
Akwa3	45 - 60	2.75	0.76	0.05	0.38	55.00	15.20	3.62
	60 - 75	2.10	2.08	0.06	0.41	35.00	34.67	1.01
	75 - 90	2.13	1.83	0.08	0.50	26.63	22.88	1.16
	90 - 105	2.09	1.22	0.07	0.54	29.86	17.43	1.71
	105 - 120	2.02	0.83	0.06	0.40	33.67	13.83	2.43
	X±SD	2.30±0.47	1.42±0.48	0.07±0.01	0.46±0.06	35.52±9.69	21.23±6.49	1.83±0.85
	0 - 15	2.55	0.34	0.36	0.49	7.08	0.94	7.50
	15 - 30	2.64	0.31	0.06	0.48	48.00	5.64	8.52
	30 - 45	2.85	1.59	0.28	0.47	10.36	5.78	1.79
Akwa4	45 - 60	2.46	1.40	0.05	0.30	49.20	28.00	1.76
	60 - 75	2.15	0.42	0.05	0.48	43.00	8.40	5.12
	75 - 90	2.82	0.36	0.05	0.41	56.40	7.20	7.83
	90 - 105	2.57	1.89	0.07	0.54	39.54	29.08	1.36
	105 - 120	3.03	0.74	0.10	0.35	31.90	7.79	4.10
	X±SD	2.63±0.27	0.88±0.65	0.13±0.12	0.44±0.08	35.69±18.15	11.60±10.70	4.75±2.95

Akwa1 – Fertilized 8years old Oil Palm field, Akwa2 – 11years old Oil Palm field, Akwa3 – 30years old Oil Palm field, Akwa4 – 60years old Oil Palm field, X - Mean, SD - Standard deviation, Ca/K – calcium to potassium ratio, Mg/K – magnesium to potassium ratio, Ca/Mg – calcium to magnesium ratio.

4.3 Some similarities between Edo and Akwa Ibom State soil quality parameters

- (1) Low in nitrogen, carbon and organic matter
- (2) High in C/N ratio
- (3) Acidic soils
- (4) Exchangeable calcium and magnesium are higher than exchangeable sodium
- (5) Low exchangeable sodium percentage
- (6) Low levels of exchangeable potassium
- (7) Low levels of boron
- (8) Size particle distribution; sandy texture
- (9) Low silt and clay content

4.4 Some difference between Edo and Akwa Ibom State soil quality parameters

- (1) The ECEC in Akwa Ibom State is higher than that of Edo State despite the fact that they are not near required levels needed for oil palm growth and development
- (2) There was a more vivid pattern of decrease of total organic carbon with depth in Edo State than in Akwa Ibom State
- (3) No exchangeable aluminium was found in the Edo State soils but exchangeable aluminium was found in the Akwa Ibom State soils
- (4) Low exchangeable acidity was found in Edo State but that of Akwa Ibom State ranges from moderate to high
- (5) The annual rainfall pattern in Edo State could not compensate for water evapotranspiration losses, but Akwa Ibom State rainfall pattern could compensate for evapotranspiration losses
- (6) Electrical conductivity in the Edo State soils was lower than that of Akwa Ibom
- (7) Despite in generally low levels of macronutrient i.e. K, Ca and N, Akwa Ibom State showed higher concentration than Edo State
- (8) Available phosphorus was lower in Edo State than in Akwa Ibom State soils
- (9) The exchangeable sodium in Edo State was lower compared to the Akwa Ibom State.
- (10) There are more silt and clay soils in Akwa Ibom State than in Edo State.

In addition, the Ed3 (49years old oil palm soil) in Edo State was found to have more clay than Ed2 (41years old palm field) and Ed1 (fallow land). In Akwa Ibom State, the Akwa1 (8years old fertilized oil palm field) had more phosphorus than Akwa2 (11years old oil palm field), Akwa3 (30years old oil palm field) and Akwa4 (60years old oil palm field).

4.5 Relationship among soil variables

Correlation coefficients calculated to assess the relationship among soil properties are presented in Table 23, 24 and 25.

Table 23. Correlation coefficients for relationship between some soil variables on the fallow land site (Reference soil) using the treatments from 8 soil samples in 8 different soil layers in Edo State

	PH	EC	TOC	TN	OM	P	Ca	Mg	Na	K	EA	BC	ECEC	C/N	Clay	Silt	Sand	Boron	ESP
PH	1																		
EC	0,852	1																	
TOC	0,796	0,733	1																
TN	0,763	0,698	0,997	1															
OM	0,797	0,736	1,000	0,997	1														
P	0,723	0,641	0,987	0,989	0,986	1													
Ca	0,434	0,337	0,823	0,836	0,821	0,855	1												
Mg	0,651	0,601	0,926	0,920	0,926	0,917	0,857	1											
Na	0,478	0,379	0,846	0,867	0,845	0,857	0,904	0,856	1										
K	0,239	0,002	0,652	0,689	0,650	0,701	0,842	0,722	0,897	1									
EA	0,497	0,368	0,408	0,408	0,411	0,390	-0,064	0,314	0,230	0,176	1								
BC	0,539	0,451	0,899	0,907	0,898	0,914	0,972	0,950	0,936	0,845	0,127	1							
ECEC	0,573	0,475	0,920	0,928	0,919	0,934	0,953	0,963	0,942	0,848	0,208	0,997	1						
C/N	-0,333	-0,287	-0,624	-0,660	-0,622	-0,583	-0,633	-0,621	-0,828	-0,772	-0,259	-0,683	-0,695	1					
Clay	-0,517	-0,413	-0,899	-0,922	-0,897	-0,913	-0,918	-0,901	-0,947	-0,894	-0,268	-0,956	-0,965	0,810	1				
Silt	0,521	0,469	0,767	0,795	0,767	0,757	0,550	0,649	0,818	0,675	0,645	0,648	0,692	-0,817	-0,787	1			
Sand	0,494	0,386	0,883	0,905	0,881	0,901	0,943	0,906	0,929	0,893	0,192	0,969	0,971	-0,775	-0,994	0,717	1		
Boron	-0,451	-0,643	-0,401	-0,353	-0,404	-0,403	-0,218	-0,336	-0,067	0,248	0,011	-0,242	-0,238	-0,355	0,052	0,039	-0,066	1	
ESP	-0,368	-0,257	-0,667	-0,658	-0,666	-0,713	-0,865	-0,791	-0,619	-0,626	0,176	-0,841	-0,815	0,247	0,704	-0,164	-0,766	0,385	1

EC-electrical conductivity, TOC-total organic carbon, TN-total nitrogen, OM-organic matter, P-available phosphorus, Ca-exchangeable calcium, Mg-exchangeable magnesium, Na-exchangeable sodium, K-exchangeable potassium, EA-exchangeable acidity, BC-exchangeable base cations, ECEC-effective cation exchange capacity, C/N-carbon to nitrogen ratio, ESP-exchangeable sodium percentage

The correlation of available boron in the fallow land with soil properties (Table 23) ranged from (0.011 – 0.643) values and showed that boron was negatively and significantly but moderately correlated with EC (-0.643). Boron was also negatively and significantly but weakly correlated with pH ($r = -0.451$), TOC ($r = -0.401$) and OM ($r = -0.404$), and these were

the best of them. Thus there was no strong correlation between boron and any of the studied soil parameters.

Table 24. Correlation coefficients for relationship between some soil variables on three sites using the treatments from 24 soil samples in 24 different soil layers in Edo State

	PH	EC	TOC	TN	OM	P	Ca	Mg	Na	K	EA	BC	ECEC	C/N	Clay	Silt	Sand	Boron	ESP
PH	1																		
EC	-0,099	1																	
TOC	0,484	0,640	1																
TN	0,454	0,561	0,941	1															
OM	0,485	0,640	1,000	0,941	1														
P	0,546	0,582	0,856	0,856	0,857	1													
Ca	0,432	0,381	0,441	0,351	0,440	0,628	1												
Mg	0,280	0,757	0,826	0,797	0,826	0,862	0,673	1											
Na	0,357	0,608	0,629	0,529	0,629	0,711	0,860	0,811	1										
K	-0,143	0,811	0,690	0,622	0,689	0,521	0,257	0,718	0,548	1									
EA	-0,374	0,381	0,239	0,190	0,240	-0,068	-0,428	0,101	-0,080	0,490	1								
BC	0,398	0,563	0,616	0,532	0,615	0,753	0,964	0,840	0,933	0,471	-0,251	1							
ECEC	0,342	0,647	0,677	0,582	0,676	0,763	0,916	0,883	0,947	0,573	-0,079	0,985	1						
C/N	0,073	-0,035	-0,007	-0,296	-0,006	-0,114	-0,014	-0,153	-0,050	-0,074	0,104	-0,057	-0,040	1					
Clay	-0,313	-0,340	-0,592	-0,462	-0,592	-0,424	0,036	-0,269	-0,228	-0,363	-0,269	-0,087	-0,138	-0,353	1				
Silt	0,429	0,371	0,399	0,303	0,399	0,616	0,939	0,635	0,837	0,229	-0,383	0,908	0,866	0,035	0,021	1			
Sand	0,274	0,306	0,554	0,433	0,554	0,368	-0,118	0,212	0,154	0,341	0,301	0,008	0,062	0,348	-0,996	-0,107	1		
Boron	0,049	0,079	0,217	0,147	0,218	0,078	0,159	0,101	0,280	0,305	0,310	0,183	0,244	-0,105	-0,045	0,108	0,035	1	
ESP	-0,159	-0,145	-0,243	-0,266	-0,242	-0,391	-0,643	-0,471	-0,291	-0,107	0,433	-0,598	-0,538	0,135	-0,363	-0,511	0,405	0,093	1

EC-electrical conductivity, TOC-total organic carbon, TN-total nitrogen, OM-organic matter, P-available phosphorus, Ca-exchangeable calcium, Mg-exchangeable magnesium, Na-exchangeable sodium, K-exchangeable potassium, EA-exchangeable acidity, BC-base cations, ECEC-effective cation exchange capacity, C/N-carbon to nitrogen ratio, ESP-exchangeable sodium percentage

The correlation of available boron in Edo State with soil properties (Table 24) ranged from (0.035 – 0.310) values. Thus in Edo State, there was no strong correlation between boron and anyone of the studied soil parameters, the best of them were exchangeable acidity and exchangeable potassium.

Table 25. Correlation coefficients for relationship between some soil variables on four sites using the treatments from 32 soil samples in 32 different soil layers in Akwa Ibom State

	pH	EC	TOC	TN	OM	P	Ca	Mg	Na	K	H	Al	BC	ECEC	C/N	Clay	Silt	Sand	B	EA	ESP
pH	1																				
EC	-0,051	1																			
TOC	-0,214	0,214	1																		
TN	-0,244	0,233	0,958	1																	
OM	-0,215	0,214	1,000	0,959	1																
P	-0,157	-0,152	-0,019	-0,045	-0,018	1															
Ca	-0,068	-0,382	0,017	0,080	0,016	-0,204	1														
Mg	0,153	-0,242	-0,177	-0,208	-0,177	0,142	0,293	1													
Na	-0,045	0,442	0,054	0,064	0,053	0,227	-0,353	-0,150	1												
K	-0,365	0,139	0,379	0,405	0,380	0,099	-0,027	-0,177	0,292	1											
H	-0,569	0,211	0,246	0,301	0,246	0,166	-0,084	-0,106	0,303	0,376	1										
Al	-0,524	-0,021	-0,015	-0,028	-0,013	0,187	-0,205	-0,026	-0,095	-0,026	0,352	1									
BC	0,022	-0,316	-0,070	-0,047	-0,070	0,007	0,771	0,805	-0,129	-0,008	-0,044	-0,169	1								
ECEC	-0,218	-0,265	-0,015	0,018	-0,015	0,084	0,693	0,758	-0,077	0,073	0,261	0,124	0,934	1							
C/N	0,204	-0,179	-0,544	-0,639	-0,544	-0,018	0,064	0,244	0,139	-0,178	-0,213	-0,115	0,213	0,135	1						
Clay	-0,261	-0,324	-0,082	-0,036	-0,081	0,312	0,228	0,191	0,079	0,120	0,086	0,199	0,291	0,346	0,240	1					
Silt	-0,009	0,201	-0,024	-0,074	-0,025	-0,010	-0,150	-0,124	0,408	0,050	0,279	-0,284	-0,103	-0,096	0,153	-0,238	1				
Sand	0,258	0,198	0,093	0,077	0,093	-0,296	-0,135	-0,114	-0,310	-0,144	-0,243	-0,030	-0,223	-0,280	-0,320	-0,832	-0,341	1			
B	0,033	-0,064	-0,122	-0,094	-0,121	-0,017	-0,083	-0,019	-0,186	-0,122	0,038	0,268	-0,108	-0,042	0,064	0,043	-0,131	0,033	1		
EA	-0,665	0,123	0,149	0,176	0,150	0,214	-0,172	-0,083	0,139	0,225	0,841	0,802	-0,126	0,238	-0,203	0,170	0,014	-0,172	0,179	1	
ESP	-0,061	0,556	0,061	0,052	0,061	0,072	-0,753	-0,582	0,718	0,204	0,205	0,093	-0,725	-0,643	-0,069	-0,224	0,325	0,031	-0,064	0,184	1

EC-electrical conductivity, TOC-total organic carbon, TN-total nitrogen, OM-organic matter, P-available phosphorus, Ca-exchangeable calcium, Mg-exchangeable magnesium, Na-exchangeable sodium, K-exchangeable potassium, H-exchangeable hydrogen, Al-exchangeable aluminium, BC-base cation, ECEC-effective cation exchange capacity, C/N-carbon to nitrogen ratio, EA-exchangeable acidity, ESP-exchangeable sodium percentage

The correlation of available boron in Akwa Ibom State with soil properties ranged from (0.017 – 0.268) values (Table 25). Thus no strong correlation was found between boron and any of the studied soil parameters and the best of them was C/N ratio. However, in principle according to Evans and Sparks (1983) availability of boron was negatively correlated with pH but this was not verified in this study because no correlation was found between pH and available B, in both Akwa Ibom State and Edo State except on the fallow land which was used as a reference soil to relate boron with pH ($r = -0.451^*$, $P \leq 0.025$).

The photographic pictures covering this study are in (Appendix 1)

5.0 CONCLUSION

- The NIFOR soils studied were characterized by predominately sandy texture and colours dark yellowish brown to black colours. They were further characterized by low pH and low concentrations of exchangeable base cations, organic carbon, total nitrogen, exchangeable boron and moderate to high levels of exchangeable acidity and C/N ratios. Based on the fertility standards (FAO, 1976), the soils were generally rated low in fertility despite the high levels of available P, Ca/K, Mg/K and base saturation.
- The low silt and clay contents, low pH, and low organic carbon, and exchangeable base cations levels were the major constraints of the soils for sustainable oil palm production. Thus, the soils were placed in the S3 category regarded as marginally suitable for oil palm production.
- The ECEC in the Akwa Ibom State was higher than that of Edo State despite the fact that they are not near the required levels needed for oil palm growth and development
- There was a more vivid pattern of decrease of total organic carbon with depth in Edo State than in Akwa Ibom State
- No exchangeable aluminium was found in the Edo State soils but there was exchangeable aluminium found in Akwa Ibom State soils
- Low exchangeable acidity was found in Edo State but that of Akwa Ibom State ranged from moderate to high
- The annual rainfall pattern in Edo State cannot compensate for water evapotranspiration losses, but the Akwa Ibom State rainfall pattern could compensate for evapotranspiration losses
- Electrical conductivity in Edo State soils was lower than that of Akwa Ibom State
- Despite the generally low levels of macronutrients i.e. K, Ca and N, Akwa Ibom State showed higher concentrations than Edo State
- Available phosphorus was lower in the Edo State than in the Akwa Ibom State soils
- There was no strong correlation between boron and any of the studied soil parameters in either Edo or the Akwa Ibom state
- The results indicate that poor soil conditions, due to soil depletion, may be one major explanation to declining productivity per ha during 1980 to 2000
- Concrete measure such as moderate organic and mineral fertilizer addition could help make the soil more productive.

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APPENDIX 1

Photographic coverage of the studied area in Edo State and Akwa Ibom State regions in Nigeria



Samples collection by the auger in Akwa Ibom State NIFOR substation by Wisdom Ofremu



Removing sample from the auger in Akwa Ibom State NIFOR substation by Wisdom Ofremu



Oil palm stands in Akwa Ibom State NIFOR substation



Driver and Dr. Philip Oviasogie, head of chemistry department division NIFOR main station in Edo State.



Fresh fruits of tenera oil palm cultivar



Fresh fruits of Dura palm cultivar



Oil palm stands of field 17 in Edo State



Examining the soil profile pit in field 10 in Edo State by Wisdom Ofremu



Soil profile pit in Akwa Ibom State



Soil profile pit in field 17 in Edo State



Layout of harvested fruits bunch in Edo State



Conveyors of fruits bunch prior to fermentation at the section of automated milling press machine in Edo State



Boiling of detached oil palm fruits from fresh fruit bunch



Shells and kernel from milled oil palm fruits in Edo State