Assessment of nutrients status of areas supporting optimum oil palm (*Elaeis guineensis Jacq. L*) cultivation in Ghana

I. DANSO*, S. A. OKYERE, E. LARBI, F. DANSO & B. N. NUERTEY
(I.D.S.A.O, E.l, F.D & B.N.N.: Council for Scientific and Industrial Research- Oil Palm Research Institute (CSIR-OPRI), P.O. Box 74, Kade, Ghana)
**Corresponding author's email: danso60@yahoo.com*

ABSTRACT

In Ghana, information on the fertility status to support oil palm growth and productivity and possible fertilizer recommendation is not common. The objective of this study was to assess the nutrition-related limitations to production of oil palm across areas climatically delineated as optimum for sustainable oil palm production. Based on Ghana Interim Soil Classification System, benchmark soils identified in these areas were: Temang (Lixisols), Akroso (Acrisol), Kokofu (Alisols), Basitia (Acrislos), Firam (Acrisols) and Nkwanta (Acrisols). Results indicated generally strongly acidic soil and exchangeable acidity values obtained were high and consistent with very acidic soil conditions. There were generally- high C: N ratios (>20) except some few sites, thus supplementary nitrogen is required to reduce C: N ratio and improve N availability. The Total Exchangeable Bases (TEB), Effective Cation Exchange Capacity (ECEC) and available P values were less than the optimum values for sustainable oil palm production. Both soil and foliar analysis indicated that soils in areas assessed have low soil fertility with relatively good soil physical conditions. It is recommended that instead of superphosphate fertilizer application, rock phosphate should be administered due to high acidity. Raising the low ECEC levels of the soil calls for composted empty fruit bunches incorporation.

Keywords: Nutrients status; rock phosphate; benchmark soils; leaf nutrient concentration; exchangeable acidity
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Introduction

Oil Palm (*Elaeis guineensis* Jacq.) belongs to the family Palmae and is a major cash crop in Ghana, contributing substantially to the national economy in terms of employment and foreign exchange earnings (ranks second to cocoa). Per hectare bases, oil palm is the most productive oil crop in the world, being 10 times more productive than soybean and other oil-bearing seeds (Verheye, 2010). Of the 17 major vegetable oils traded on the international market, palm oil is the most important and accounts for more than half of the global import and export trade of all vegetable oils (Boons & Angelica, 2010).

Ghana was the first country where the British established oil palm plantations in the 19th century (Aghalino, 2000). The same seeds and production techniques were then used to establish palm oil estates in another British colony-Malaysia. Despite the common root, the palm oil value chain in Malaysia and Ghana took two divergent development pathways. Malaysia is now the world's second-largest palm oil producer and exporter after Indonesia, while Ghana ranks 10th in terms of production quantity (520,000 MT) (USDA, 2017). Yield potential is much higher, with annual yields of up to 25.2 t ha^{-1} observed in research trials in Ghana (Danso *et al.,* 2008) but up to 4 t ha^{-1} being obtained in small-scale farmer's fields which constitute about 80% of the total area under oil palm cultivation in Ghana. The underdevelopment of oil palm industry in Ghana among others may be attributed to: the use of uncertified planting materials, lack of appropriate agronomic knowledge, use of inefficient processing equipment, inadequate labor, lack of access to credit facilities and low pricing conditions due to poor oil quality production.

Oil palm a perennial crop has an economic lifespan ranging between 25-30 years (Hartley, 1988). The continuous removal of nutrients through Fresh Fruit Bunches (FFB) harvest results in declining soil fertility. This causes a serious decrease in yield per unit area narrowing the financial base of the small-scale oil palm farmer.

For good growth and productivity, the oil palm must thrive well under optimum soil conditions with total N, available P, and available K of 0.2%, 20 mg/kg and 100 mg/kg respectively (Hartley, 1988). According to Goh and Chew (1997), other soil fertility parameters must also be present in the soil within suitable ranges. For instance, oil palm thrives well under CEC of 15-18 cmol kg^{-1}, pH of 5.0-5.5, exchangeable K of 0.25-0.30 cmol kg^{-1} and exchangeable Mg of 0.25-0.3 cmol kg^{-1}. High fertility status of the supporting soils is therefore required for high productivity of oil palm per unit land area. In Ghana, information on the fertility status to support oil palm growth and productivity and possible fertilizer recommendation is not common.

The objective of this study was to assess the nutrition-related limitations to the production of oil palm across areas climatically delineated (Figure 1) as optimum for oil palm production in Ghana.

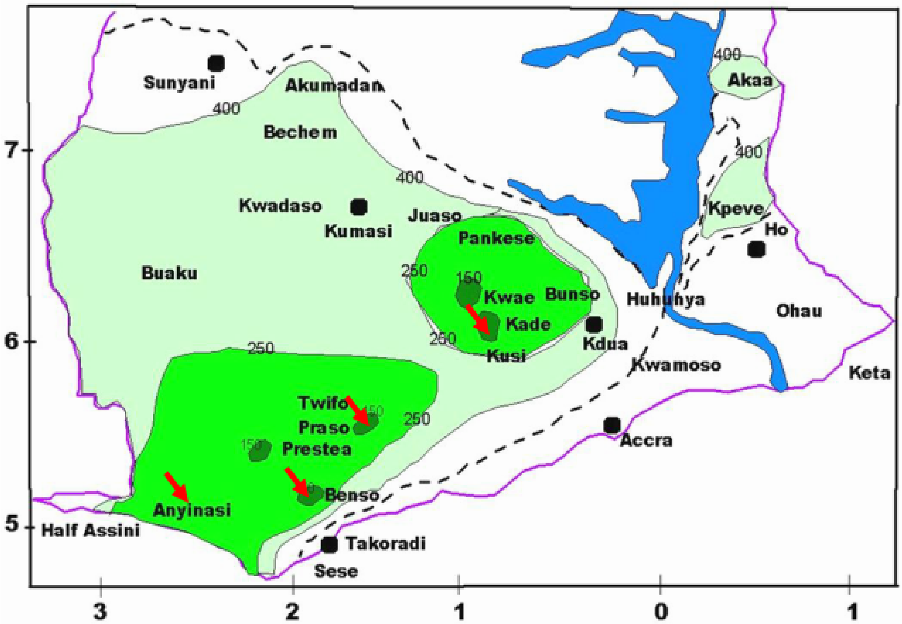
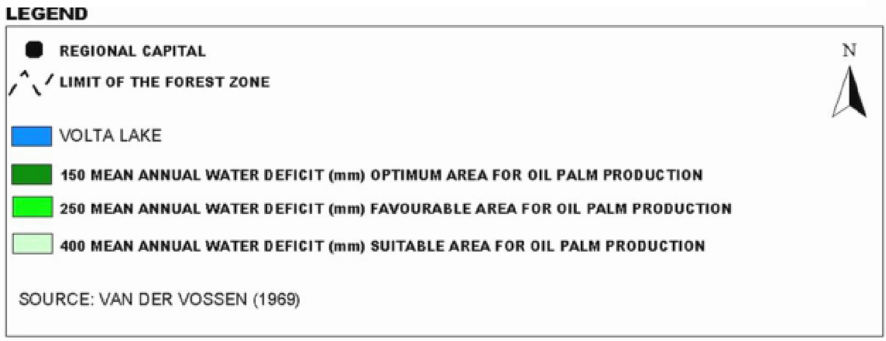


Fig. 1: Areas (arrowed) selected for nutritional status determination which falls in zones climatically optimum for oil palm cultivation in Ghana



Materials and Methods

Sites description

Eight sites (Figure 1) were selected (Kusi I, Kusi II, Norpalm, TOPP, Benso I, Benso II, Benso III and Aiyanase) for characterization with oil palm trees with ages ranging from 10 to 12 years across sites. The selected sites fall within the zone climatically classified as optimum (Figure 1) for oil palm cultivation in Ghana (Van der Vossen, 1969). The areas are characterized by relatively high rainfall occurring in two seasons (bi-modal). With oil palm requiring between 1500-2000 mm annual amount of rainfall, the mean annual rainfall for the sites is 1120 mm. The major rainy season starts from April and ends in July whilst the minor season spans between September and mid-November. The major dry season occurs between the end of the minor wet season and the next major wet season. Temperatures are generally high and uniform throughout the year. The mean monthly temperatures range from 24 to 30^{0}C. The month of July records the lowest mean monthly temperature of about 24^{0}C, while March records the highest of 30^{0}C.

Relative humidity at the sites is about 90% at 0600 hours and falling to between 70 and 50% at 1500 hours. In the wet season, relative humidity is high (about 96%) while it is low (about 40%) in the dry season.

Soil profile characterization (Figure 2) was done for each site and soils sampled were classified based on Ghana Interim Soil Classification System (Brammer, 1962) and subsequently correlated to World Reference Base (WRB) soil names (FAO, 1998).

Fig. 2: Soil profile for characterization =in one of the sites

Soil sampling

Soil profile pits were dug and samples were taken from 0-20, 20-40, 40-60,60-80 and 80-100 cm soil depths at different sites for laboratory analysis. Samples were placed on drying trays in the drying room for 24 hours. They were then ground and passed through a 2 mm diameter nylon sieve and subjected to the following analytical methods.

Laboratory analysis

Soil

Soil pH was measured in a 1:2.5 soil: water suspension using a HI 9017 microprocessor pH meter. The modified Walkley and Black procedure as described by Nelson and Sommers (1982) were used to assess the organic C content of the soils. Total N was determined by Kjeldahl digestion method. The available P was extracted with an HCl: NH_4F solution as described by Bray and Kurtz (1945) and determined colorimetrically using the molybdenum blue method. Exchangeable bases (calcium, magnesium, potassium and sodium) in the soil were determined in 1.0 M ammonium acetate extract whilst exchangeable acidity (hydrogen and aluminium) was determined in 1.0 *M* KCl extract. The Effective Cation Exchange Capacity (ECEC) was calculated as the sum of exchangeable bases and exchangeable acidity. Soil particle size was determined using the hydrometer method (Bouyoucos, 1962).

Foliar nutrient analysis

Leaf samples of the oil palm lamina from the central leaflets of leaf No. 17 (representative leaf for nutrient concentration analysis) was sampled and analysed for nutrient concentration. Samples were cleaned thoroughly with cotton wool and distilled water and oven-dried in an oven at 70^{0}C for 48 hours to a constant weight. The oven dried leaf samples were milled to pass through 0.5 mm sieve mesh. Determination of total nitrogen, phosphorus, potassium, calcium and magnesium using the standard methods (IITA, 1982).

Results and Discussion

Benchmark soils

Soils studied in the eight sites are categorized according to the Ghana Interim Soil Classification System (Brammer, 1962) and World Reference Base (FAO, 1998) (Table 1).

TABLE 1
Benchmark soils identified and World Reference Base (W.R.B) classification (FAO,1998)

Site	*Soil series*	*Parent materials*	*FAO (1998)*
Kusi I	Temang	Birimian	Lixisols
Kusi II	Temang	Birimian	Lixisols
Norpalm	Akroso	Granite	Acrisols
TOPP	Kokofu	Birimian	Alisols
Aiyinase	Basitia	Tertiary sand	Acrisols
Benso I	Firam	Granite	Acrisols
Benso II	Nkwanta	Granite	Acrisols
Benso III	Akroso	Granite	Acrisols

Chemical properties of soil

The chemical properties of the soils (0-100 cm soil depth) for the oil palm fields at the eight sites are shown in Tables 2a-2c.

Soil reaction

The pH values ranged from 3.81 at Kusi I to 4.65 at Kusi II site. The values obtained suggest that the pH values of the soil samples were very strongly acidic. Exchangeable acidity ranged from 0.25 to1.5 cmol/kg and generally increased with depth. The low pH values of the soil were similar to those reported for some Ghanaian soils by Adu and Tenadu (1979). Strong leaching of the basic cations out of the topsoil contributed to low pH values. This pH values recorded are very low and have a negative influence on the production potential of the crop since pH values are below the minimum value of 5.0 suitable for oil palm growth.

Exchangeable cations

Mean values of exchangeable Ca, Mg, K and Na values for the various sites are low (Table 2a-2c). The total exchangeable bases values are very low at TOPP with a mean value of 1.91 cmol/kg. The exchangeable bases concentration decreased with increasing soil depth, indicating leaching of these nutrients from the topsoil to the deeper layers. Exchangeable sodium concentrations in all the eight sites do not pose any threat to the effective growth of oil palm (Table 2a-2c). The effective cation exchange capacity (ECEC) values were less than 15 cmol/kg soil across all the sites sampled, an indication that their soil nutrient retaining abilities are very low and therefore necessitate the application of fertilizers (Rhoades, 1982). The low ECEC values could be attributed to the low soil organic matter content and to the fact that the clay fraction is dominated by low activity clays (kaolinitic) (Owusu-Bennoah *et al.,* 1996).

Organic matter, total nitrogen and organic carbon

Organic matter and total nitrogen are positively correlated since much of the nitrogen are due to mineralization of organic matter. Both values in all the eight sites (2a-2c) analysed decreased with increasing soil depth and were below the acceptable limits for oil palm growth as indicated by Hartley (1988). The percentage organic carbon present was higher for the surface soil than for the deeper layers and the values obtained correspond with those reported by Ukpebor *et al.* (2003).

The values across sites were low for oil palm cultivation when compared with values of 3.0% which Chan (1978) considered as optimum value for oil palm growth and good yield response. The very low organic carbon content reflected the generally highly weathered soils in the humid rainforest agro-ecological zone of the country (Owusu-Bennoah *et al.,* 2000).

C: N ratio

The C: N ratio for the sites Kusi II and Norpalm (Table 2a-2c) were low and are within the range of soil organic matter that can easily mineralize without serious immobilization of nitrogen. On the other hand, the C: N ratio for the remaining sites Aiyinase, TOPP, Kusi I, Benso I, Benso II and Benso III is relatively high. Hence, additional organic materials rich in nitrogen would be required to reduce the C: N ratio and aid mineralization provided the humic materials are not in a stable state.

Available P

The mean value for available P was very low for the sites studied and ranged from 0.26 mg/kg at Aiyinase to 3.07 mg/kg at Benso I site. The available P content indicated that the soil was extremely deficient in P. According to Hartley (1988), the threshold deficiency for P is 10 mg/kg. This could be attributed to the advanced stage of weathering of the parent rocks which lacked primary weatherable minerals necessary for nutrient recharge (Charreau, 1974). Although all inorganic P cannot be considered sorbed P, these findings together with the Bray P results strongly suggest deficiency of P in the soils and hence, the need for P fertilizer application.

TABLE 2A
Chemical properties of soils sampled at various soil depth

site	Sample depth	pH (1:2.5 H_2O)	Org. C (%)	Org. M. (%)	Total N (%)	Avail. P (mg/kg)	Avail. K(cmol/kg)	Exch. Cations cmol/kg				Exch. TEB (cmol/kg)	Exch. Acidity (cmol/kg)	C:N ratio	ECEC (cmol/kg)	Base.sat. (%)
								Mg^{2+}	K^{+}	Na^{+}	Ca^{2+}					
	0-20	4.06	1.34	2.31	0.11	4.40	31.05	0.96	0.13	0.14	3.84	5.07	1.45	12.18	6.52	77.76
	20-40	4.03	1.11	1.91	0.05	0.40	62.05	0.32	0.13	0.20	4.32	4.97	0.85	22.2	5.82	85.40
Kusi I	40-60	4.01	1.01	1.74	0.04	0.35	56.01	0.30	0.12	0.25	3.45	4.12	0.90	25.25	5.02	82.07
	60-80	3.90	0.90	1.55	0.04	0.30	54.10	0.29	0.09	0.27	3.89	4.54	1.00	22.5	5.54	81.95
	80-100	3.81	0.85	1.46	0.31	0.29	53.23	0.24	0.07	0.29	3.88	4.48	1.05	2.74	5.53	81.01
	Mean	3.96	1.04	1.79	0.11	1.15	51.29	0.42	0.11	0.23	3.88	4.64	1.05	16.97	5.69	81.64
	0-20	4.20	1.05	1.81	0.10	0.80	69.20	1.60	0.07	0.15	2.88	4.70	0.25	10.5	4.95	94.95
	20-40	4.78	0.44	0.76	0.09	0.40	59.70	0.40	0.06	0.20	2.40	3.06	0.30	4.9	3.36	89.46
Kusi	40-60	4.71	0.43	0.74	0.08	0.90	70.00	0.41	0.04	0.21	2.54	3.20	0.36	5.37	3.56	89.89
II	60-80	4.66	0.41	0.71	0.07	0.93	65.23	0.30	0.05	0.19	2.64	3.18	0.41	5.86	3.59	88.58
	80-100	4.65	0.39	0.68	0.06	0.95	68.23	0.31	0.06	0.23	2.50	3.10	0.40	6.5	3.50	88.57
	Mean	4.60	0.54	0.94	0.08	0.80	66.47	0.60	0.06	0.20	2.60	3.45	0.34	6.63	3.79	90.29
	0-20	4.03	0.91	1.57	0.07	1.45	59.70	0.80	0.07	0.18	2.72	3.77	1.00	13.0	4.77	79.04
	20-40	4.13	0.56	0.97	0.06	0.20	131.30	0.64	0.06	0.08	1.44	2.22	1.05	9.3	3.27	67.89
Norpa-Im	40-60	4.11	0.51	0.88	0.05	0.42	98.22	0.75	0.07	0.19	1.45	2.46	0.94	10.2	3.40	72.35
	60-80	4.12	0.50	0.86	0.04	0.39	93.00	0.72	0.59	0.09	1.65	3.05	0.96	12.5	4.01	76.06
	80-100	4.15	0.49	0.84	0.03	0.40	123.11	0.76	0.61	0.18	1.52	3.07	0.98	16.3	4.05	75.80
	Mean	4.11	0.49	1.02	0.05	0.57	101.07	0.73	0.28	0.14	1.76	2.91	0.99	12.26	3.90	74.22
	0-20	4.10	0.62	1.07	0.11	1.20	47.75	0.48	0.09	0.07	1.60	2.24	0.40	5.64	2.64	84.85
	20-40	4.40	0.31	0.53	0.01	0.20	38.20	0.48	0.08	0.14	2.40	3.10	0.30	31	3.40	91.18
TOPP	40-60	4.45	0.30	0.51	0.01	1.10	39.01	0.47	0.07	0.12	0.70	1.36	0.30	30	1.66	81.93
	60-80	4.43	0.29	0.49	0.01	0.89	38.41	0.46	0.08	0.13	0.80	1.47	0.31	29	1.78	82.58
	80-100	4.41	0.27	0.46	0.01	0.80	37.91	0.44	0.06	0.12	0.78	1.40	0.30	27	1.70	82.35
	Mean	4.36	0.36	0.61	0.03	0.84	40.26	0.47	0.08	0.12	1.26	1.91	0.32	18.95	2.24	84.56
site	Sample depth	pH(1:2.5H_2O)	Org. C (%)	Org.M (%)	Total N (%)	Avail.P (mg/kg)	Avail.K (cmol/)	Exch. Cations coml/kg				Exch. TEB (cmol/kg)	Exch. Acidity (cmol/kg)	C:N ratio	ECEC (cmol/kg)	Base sat. (%)
								Mg^{2+}	K^{+}	Na^{+}	Ca^{2+}					
	0-20	4.54	2.07	3.57	0.07	0.40	88.3	0.96	0.15	0.17	6.08	7.36	0.30	29.6	7.66	96.08
	20-40	4.48	1.42	2.45	0.05	0.20	90.70	0.88	0.12	0.06	3.84	4.90	0.65	28.4	5.55	88.29
Aiyan-ase	40-60	4.45	1.40	2.42	0.05	0.23	91.32	0.87	0.11	0.15	3.12	4.25	0.63	28	4.88	87.09
	60-80	4.46	1.39	2.40	0.04	0.21	90.23	0.86	0.12	0.11	3.22	4.31	0.62	34.75	4.93	87.42
	80-100	4.44	1.40	2.42	0.03	0.25	89.34	0.84	0.09	0.12	3.01	4.06	0.61	46.66	4.67	86.93
	Mean	4.47	1.54	2.65	0.05	0.26	89.98	0.88	0.12	0.12	3.85	4.98	0.65	33.48	5.54	89.16
	0-20	4.04	3.81	6.57	0.11	3.20	76.40	1.60	0.08	0.19	3.84	5.71	0.50	34.6	6.21	91.95
	20-40	4.09	2.48	4.28	0.10	3.00	45.35	0.64	0.07	0.13	3.52	4.36	0.90	24.8	5.26	82.89
Benso I	40-60	4.07	2.43	4.19	0.10	3.01	47.34	0.65	0.05	0.14	3.45	4.29	0.89	24.3	5.18	82.82
	60-80	4.04	2.41	4.16	0.09	3.11	48.65	0.63	0.06	0.13	3.34	4.16	0.88	26.77	5.04	82.54
	80-100	4.06	2.39	4.13	0.08	3.02	49.77	0.71	0.07	0.12	3.53	4.43	0.90	29.88	5.33	83.11
	Mean	4.06	2.70	4.67	0.10	3.07	53.50	0.82	0.07	0.14	3.53	4.59	0.81	17.54	5.40	84.66
	0-20	3.95	1.65	2.84	0.11	1.00	54.90	0.64	0.09	0.03	1.60	2.36	1.20	15.0	3.56	66.29
	20-40	3.92	1.28	2.21	0.03	0.20	78.75	0.56	0.12	0.20	3.20	4.08	1.50	42.7	5.58	73.12
Benso II	40-60	3.93	1.27	2.19	0.03	0.23	75.34	0.60	0.10	0.23	2.56	3.49	1.43	42.33	4.92	70.93
	60-80	3.92	1.24	2.14	0.02	0.24	76.30	0.58	0.09	0.27	2.60	3.54	1.37	62	4.91	72.10
	80-100	3.91	1.23	2.12	0.01	0.20	77.54	0.61	0.08	0.26	2.57	3.52	1.35	123	4.87	72.28
	Mean	3.93	1.33	2.3	0.04	0.37	72.57	0.60	0.10	0.20	2.51	3.40	1.37	57.01	4.77	70.94

TABLE 2B

Chemical properties of soil sampled at various soil depth

site	Sample depth	pH (1:2.5 H_2O)	Org. C (%)	Org. M. (%)	Total N (%)	Avail. P (mg/kg)	Avail. K(cmol/kg)	Exch. Cations cmol/kg				Exch. TEB (cmol/kg)	Exch. Acidity (cmol/kg)	C:N ratio	ECEC (cmol/kg)	Base. sat. (%)
								Mg^{2+}	K^+	Na^+	Ca^{2+}					
	0-20	4.06	1.34	2.31	0.11	4.40	31.05	0.96	0.13	0.14	3.84	5.07	1.45	12.18	6.52	77.76
	20-40	4.03	1.11	1.91	0.05	0.40	62.05	0.32	0.13	0.20	4.32	4.97	0.85	22.2	5.82	85.40
Kusi I	40-60	4.01	1.01	1.74	0.04	0.35	56.01	0.30	0.12	0.25	3.45	4.12	0.90	25.25	5.02	82.07
	60-80	3.90	0.90	1.55	0.04	0.30	54.10	0.29	0.09	0.27	3.89	4.54	1.00	22.5	5.54	81.95
	80-100	3.81	0.85	1.46	0.31	0.29	53.23	0.24	0.07	0.29	3.88	4.48	1.05	2.74	5.53	81.01
	Mean	3.96	1.04	1.79	0.11	1.15	51.29	0.42	0.11	0.23	3.88	4.64	1.05	16.97	5.69	81.64
	0-20	4.20	1.05	1.81	0.10	0.80	69.20	1.60	0.07	0.15	2.88	4.70	0.25	10.5	4.95	94.95
	20-40	4.78	0.44	0.76	0.09	0.40	59.70	0.40	0.06	0.20	2.40	3.06	0.30	4.9	3.36	89.46
Kusi	40-60	4.71	0.43	0.74	0.08	0.90	70.00	0.41	0.04	0.21	2.54	3.20	0.36	5.37	3.56	89.89
II	60-80	4.66	0.41	0.71	0.07	0.93	65.23	0.30	0.05	0.19	2.64	3.18	0.41	5.86	3.59	88.58
	80-100	4.65	0.39	0.68	0.06	0.95	68.23	0.31	0.06	0.23	2.50	3.10	0.40	6.5	3.50	88.57
	Mean	4.60	0.54	0.94	0.08	0.80	66.47	0.60	0.06	0.20	2.60	3.45	0.34	6.63	3.79	90.29
	0-20	4.03	0.91	1.57	0.07	1.45	59.70	0.80	0.07	0.18	2.72	3.77	1.00	13.0	4.77	79.04
	20-40	4.13	0.56	0.97	0.06	0.20	131.30	0.64	0.06	0.08	1.44	2.22	1.05	9.3	3.27	67.89
Norpa-	40-60	4.11	0.51	0.88	0.05	0.42	98.22	0.75	0.07	0.19	1.45	2.46	0.94	10.2	3.40	72.35
lm	60-80	4.12	0.50	0.86	0.04	0.39	93.00	0.72	0.59	0.09	1.65	3.05	0.96	12.5	4.01	76.06
	80-100	4.15	0.49	0.84	0.03	0.40	123.11	0.76	0.61	0.18	1.52	3.07	0.98	16.3	4.05	75.80
	Mean	4.11	0.49	1.02	0.05	0.57	101.07	0.73	0.28	0.14	1.76	2.91	0.99	12.26	3.90	74.22
	0-20	4.10	0.62	1.07	0.11	1.20	47.75	0.48	0.09	0.07	1.60	2.24	0.40	5.64	2.64	84.85
	20-40	4.40	0.31	0.53	0.01	0.20	38.20	0.48	0.08	0.14	2.40	3.10	0.30	31	3.40	91.18
TOPP	40-60	4.45	0.30	0.51	0.01	1.10	39.01	0.47	0.07	0.12	0.70	1.36	0.30	30	1.66	81.93
	60-80	4.43	0.29	0.49	0.01	0.89	38.41	0.46	0.08	0.13	0.80	1.47	0.31	29	1.78	82.58
	80-100	4.41	0.27	0.46	0.01	0.80	37.91	0.44	0.06	0.12	0.78	1.40	0.30	27	1.70	82.35
	Mean	4.36	0.36	0.61	0.03	0.84	40.26	0.47	0.08	0.12	1.26	1.91	0.32	18.95	2.24	84.56
site	Sample depth	pH(1:2.5H_2O)	Org. C (%)	Org.M (%)	Total N (%)	Avail.P (mg/kg)	Avail.K (cmol/)	Exch. Cations coml/kg				Exch. TEB (cmol/kg)	Exch. Acidity (cmol/kg)	C:N ratio	ECEC (cmol/kg)	Base sat. (%)
								Mg^{2+}	K^+	Na^+	Ca^{2+}					
	0-20	4.54	2.07	3.57	0.07	0.40	88.3	0.96	0.15	0.17	6.08	7.36	0.30	29.6	7.66	96.08
	20-40	4.48	1.42	2.45	0.05	0.20	90.70	0.88	0.12	0.06	3.84	4.90	0.65	28.4	5.55	88.29
Aiyan-	40-60	4.45	1.40	2.42	0.05	0.23	91.32	0.87	0.11	0.15	3.12	4.25	0.63	28	4.88	87.09
ase	60-80	4.46	1.39	2.40	0.04	0.21	90.23	0.86	0.12	0.11	3.22	4.31	0.62	34.75	4.93	87.42
	80-100	4.44	1.40	2.42	0.03	0.25	89.34	0.84	0.09	0.12	3.01	4.06	0.61	46.66	4.67	86.93
	Mean	4.47	1.54	2.65	0.05	0.26	89.98	0.88	0.12	0.12	3.85	4.98	0.65	33.48	5.54	89.16

TABLE 2C
Chemical properties of soils sampled at various soil depth

site	Sample depth	pH(1:2.5 H_2O)	Org. C (%)	Org.M (%)	Total N (%)	Avail. P (mg/kg)	Avail.K (Cmol/kg)	Exch. Cations cmol/kg				Exch. TEB (cmol/kg)	Exch. Acidity (cmol/kg)	C:N ratio	ECEC (cmol/kg)	Base sat.(%)
								Mg^{2+}	K^+	Na^+	Ca^{2+}					
Benso III	0-20	4.30	1.71	2.95	0.08	0.80	81.15	0.64	0.12	0.15	3.36	4.27	0.60	21.4	4.87	87.68
	20-40	4.22	0.95	1.64	0.03	0.20	91.90	0.80	0.12	0.13	2.88	3.93	0.90	31.7	4.83	81.37
	40-60	4.12	0.94	1.62	0.07	0.30	90.30	0.78	0.13	0.12	2.78	3.81	0.78	13.43	4.59	83.01
	60-80	4.23	0.91	1.57	0.06	0.31	91.32	0.74	0.11	0.11	2.67	3.63	0.81	15.16	4.44	81.76
	80-100	4.20	0.90	1.55	0.05	0.30	90.10	0.76	0.12	0.11	2.89	3.88	0.84	18	4.72	82.20
	Mean	4.21	1.08	1.87	0.06	0.38	88.95	0.74	0.12	o.12	2.92	3.90	0.79	19.94	4.69	83.20

Physical properties of soils at the sites

For the particle size analysis, the soils were found to be mainly coarse with the percentage of sand ranging from 34.4 to 88.4% (Table 3a-3b). Sand contents were generally higher in the surface layers of soil as compared to deeper layers. Silt content varied from 4.7% for deeper layers at Norpalm to 46.5% for surface layers at Kusi I. On the other hand, clay contents were moderate and ranged from 5.0 to 42.2% across the eight sites. The particle size of soil and texture are important factors determining the fertility status of soils that supports the cultivation of oil palm. According to Hartley (1988), for optimum oil palm production, the soil must be deep and loamy with a well-developed structure. Soil should have a loose, friable consistency and must be without impervious layers in the top 1.5 metres. This is because the efficient root system of the oil palm is not strong enough to penetrate hard layers and will flourish and give better yields if the surface soil is physically suitable and chemically rich. The areas sampled had no hardpan within 0-100 cm depth to obstruct penetration of roots.

TABLE 3A

Physical properties of soils sampled at various soil depth at the sites

Site	*Soil Depth (cm)*	*Sand (%)*	*Silt (%)*	*Clay (%)*	*Texture*
	0-20	34.5	46.5	19.0	Loam
	20-40	40.0	37.0	23.0	Loam
Kusi I	40-60	39.0	28.0	33.0	Clay loam
	60-80	38.9	25.1	34.9	Clay loam
	80-100	34.4	23.4	42.2	Clay
	0-20	68.0	27.0	5.0	Sandy loam
	20-40	60.0	32.0	8.0	Sandy loam
Kusi II	40-60	53.1	34.6	12.3	Sandy loam
	60-80	47.4	38.0	14.6	Loam
	80-100	32.5	51.1	16.4	Silt loam
	0-20	75.5	14.5	10.0	Sandy loam
	20-40	75.5	14.5	10.0	Sandy loam
Norpalm	40-60	78.3	9.6	12.1	Sandy loam
	60-80	79.2	6.6	14.4	Sandy loam
	80-100	80.3	4.7	15.0	Sandy loam
	0-20	85.0	10.0	5.0	Loamy sand
	20-40	87.0	8.0	5.0	Loamy sand
TOPP	40-60	88.4	4.6	7.0	Loamy sand
	60-80	86.0	6.5	7.5	Loamy sand
	80-100	87.0	5.2	7.8	Loamy sand

TABLE 3B

Physical properties of soil sampled at various soils depth at the sites

Site	***Soil depth (cm)***	***Sand (%)***	***Silts (%)***	***Clay (%)***	***Texture***
	0-20	67.0	19.0	14.0	Sandy loam
	20-40	49.0	24.0	27.0	Sandy clay loam
Aiyanasi	40-60	45.2	18.8	36.0	Sandy clay
	60-80	42.3	19.3	38.4	Clay loam
	80-100	40.1	19.6	40.3	Clay
	0-20	74.0	19.0	7.0	Loamy sand
	20-40	82.5	12.5	5.0	Loamy sand
Benso I	40-60	83.2	8.5	8.3	Loamy sand
	60-80	83.1	7.5	9.4	Loamy sand
	80-100	84.5	5.2	10.3	Loamy sand
	0-20	59.5	22.5	18.0	Sandy loam
	20-40	56.2	17.8	26.0	Sandy clay loam
Benso II	40-60	55.3	16.4	28.3	Sandy clay loam
	60-80	52.3	18.3	29.4	Sandy clay loam
	80-100	50.1	15.5	34.4	Sandy clay loam
	0-20	67.5	17.5	15.0	Sandy loam
	20-40	64.5	15.5	20.0	Sandy loam
Benso III	40-60	63.2	13.4	23.4	Sandy clay loam
	60-80	62.3	13.5	24.2	Sandy clay loam
	80-100	60.3	14.4	25.3	Sandy clay loam

Leaf nutrient concentration

The leaf nutrients concentrations across the eight sites are presented in Table 4. The results generally show that the N, K, and Ca contents were low and could affect the productivity of the palms negatively. Phosphorus concentration was inadequate for three sites (Kusi I, Kusi II and Norpalm). Results show that Mg concentration is above the 0.25% critical value by Fairhusrst and Von Uexkull (1999) below which fertilizer should be applied across the eight sites.

Of all the nutrients analyzed (N, P, K, Mg and Ca), N, Ca and K were below the critical nutrient levels of 0.6 0.5 and 1.0% respectively (IRHO, 1960). The low levels could be attributed to the low contents of N, Ca and K in the soil medium which was far below the threshold deficiency levels (Tables 2a-2c). Noggle and Engelstad (1972) observed in their fertilizer experiment that, in cases of severe deficiency of nutrients in the soil, nutrient concentration in plants decreases. Antagonistic effects on plant nutrient levels have been reported by Bah and Zararah (2004). They observed in their study that, availability of K in oil palm leaves depended on leaf Mg content with increasing Mg leading to reduction in leaf K content. Results obtained in this study confirmed their study with increased

Mg concentration resulting in decreased K during the period of investigation. Fertilizer recommendation studies by Council for Scientific and Industrial Research-Oil Palm Research Institute (1986) indicated that mature oil palm may not need Mg since percent leaf Mg contents are generally above the critical leaf nutrient levels of 0.24% (IRHO, 1960). This work confirms their findings since leaf Mg contents in this study were above 0.24%. The N-deficiency in the palm leaves may usually be associated with conditions of waterlogging, ineffective weed management strategies and topsoil erosion. Extended N deficiency normally reduces the number of effective fresh fruit bunches produced as well as the bunch size.

TABLE 4
Leaf nutrient concentration (%)

Site	*N*	*P*	*K*	*Ca*	*Mg*
Kusi I	1.83	0.12	0.08	0.12	0.33
Kusi II	1.82	0.14	0.11	0.13	0.38
Norpalm	1.70	0.13	0.09	0.12	0.34
TOPP	2.20	0.19	0.41	0.15	0.60
Aiyanase	1.91	0.18	0.51	0.16	0.59
Benso I	1.86	0.2 0	0.58	1.98	0.42
Benso II	1.93	0.18	0.48	1.47	0.53
Benso III	1.97	0.19	0.52	1.57	0.30

Conclusion and Recommendation

Soil physical properties were found to be generally good at the eight sites. The main problem regarding the soils was the low levels of fertility elements. The sites were strongly acidic and exchangeable cations were low with low to very low available phosphorus. Due to the high rainfall regime of the areas, organic matter, organic carbon and total nitrogen were generally low to support good growth of palms. Leaf nutrient concentrations across sites were below the critical values below which nutrients should be applied except Mg.

Drastic improvement of fertility levels of these soils is therefore required for improvement of oil palm production in these areas. Improvement of ECEC of these sites is necessary through the incorporation of empty fresh fruit bunches and the strongly acidic condition of the sites could be reversed through lime and rock phosphate application instead of superphosphate. Additionally, the use of lime, application of appropriate mineral fertilizers as well as maintenance of leguminous cover crops could improve the fertility status of these soils.

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