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Oil Palm Fertiliser Recommendation for Sabah Soils

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ABSTRACT

This article discusses on derivation of oil palm fertiliser formulation based on nutrient budget in Sabah mineral soils. The balanced compound fertiliser with N:11%, P_2O_5:6%, K_2O: 22%, MgO: 2% and B_2O_3: 0.5% were fortified with organic matter and premium grade trace elements. This formulation would enhance the nutrient uptake and thus improving productivity of oil palm. Recycling of organic matter from palm waste would reduce the production cost towards sustainable oil palm plantation. The nutrients ratio of compound fertilisers available in the market were ranged between 23.5% to 48%. Therefore, this formulation with 41.5% of the nutrient ratio is considered commendable. The recommendation fertiliser rate for this formulation to be applied in mature oil palm is 8.5 to 9.0 kg palm^{-1} yr^{-1}.

ABSTRAK

Artikel ini membincangkan bagaimana untuk memperoleh formulasi baja sawit berdasarkan kegunaan nutrien di tanah di Sabah. Baja sebatian yang seimbang dengan nisbah N: 11%, P_2O_5:6%, K_2O:22%, MgO:2% dan B_2O_3:0.5% serta diperkaya dengan bahan organik dan unsur surih gred premium akan meningkatkan pengambilan nutrien dan produktiviti sawit. Pengitaran semula bahan organik daripada sisa sawit akan mengurangkan kos pengeluaran sawit dan menjadikan industri tersebut lebih mampan. Jumlah keseluruhan nisbah nutrien dalam baja sebatian sawit yang terdapat di pasaran adalah antara 23.5% - 48%. Oleh itu, formulasi baja dengan jumlah keseluruhan nutrien baja sebanyak 41.5% adalah munasabah. Kadar syor pembajaan adalah di antara 8.5 - 9.0 kg pk^{-1} thn^{-1} untuk pokok sawit matang.

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INTRODUCTION

The oil palm yield potential is basically dependent on nutrient use efficiency. Since fertiliser is the most important input in oil palm cultivation, thus it has to be applied efficiently to ensure optimum returns from its application. Fertiliser requirement is based on plant nutrient uptake, removal, immobilisation in plant, and loss in the system. Balanced fertiliser applied according to site specific nutrient management, which is crucial for sustained and profitable palm oil production. Although nutrient requirement is site specific, a balanced compound fertiliser for oil palm is essential to attain the sufficient nutrient demands for several locations. Variations in soil fertility and high annual rainfall in Sabah favoured the application of compound fertiliser as it could reduce the fertiliser application rounds. In addition, the fertiliser cost could be further lowered if the compound fertiliser is to be produced in Sabah rather than importing from Peninsular Malaysia.

In order to derive the balanced nutrients ratio, 13 major soil families having morphological, physical and chemical characteristic suitable for oil palm cultivation were selected in Sabah. They were Apas, Bengawat, Buran, Inanam, Kelawat, Koyah, Kumansi, Lumisir, Lumpongan, Paliu, Pinianakan, Table and Tanjung Lipat. The results showed that, about 38%, 84.6% and 69.2% of these soils were classified as low in nitrogen (N), phosphorus (P) and potassium (K) respectively as shown in *Table 1*.

This implied that high requirement of P and K in compound fertiliser is needed for Sabah soils. The content of magnesium (Mg) in Sabah soils is high, therefore the Mg requirement is considered minimal. Unfortunately, the existing MPOB fertiliser formulations do not conform to the estimated oil palm nutrients requirement for Sabah soils.

OBJECTIVE

To derive the optimum oil palm nutrients ratio for Sabah mineral soils based on their diverse characteristics and fertility status.

EXPECTED BENEFIT

Balanced fertiliser recommendation would increase the nutrient uptake and enhanced oil palm productivity in a variety of mineral soils in Sabah.

DERIVATION OF DATA FOR NUTRIENT FORMULATION

The nutrient ratio for fertiliser suited for Sabah soils is based on the followings:

- nutrient level of selected Sabah soils at A and B horizons and their soil fertility status;
- total nutrient requirement, considering the oil palm and environmental demands (*e.g.*; removal, immobilisation and lost);
- the optimum nutrient ratio for oil palm growth and yield production (28 to 30 t $ha^{-1}yr^{-1}$ of fresh fruit bunch (FFB) yield); and
- the fertiliser formulation that takes into account the fortifying of inorganic, organic fertilisers and supreme soil conditioner which can increase the efficiency of nutrient uptake by the crops and enhance the long-term retention of soil nutrients as to improve the soil quality.

Soil Chemicals Analysis

The soil chemical analyses data was obtained and recalculated from the Soil Familiarisation and Soil Management Tour held at Tawau/Semporna, Sandakan, Sabah; Kuching - Samarahan, Sarawak and Dent Peninsula of Sabah (Paramanathan, 1997; 1999; 2001). In Sabah soil classification units are further subdivided into soil families which are distinguished by soil texture and the nature of parent materials. A total of 107 soil families have been identified to-date in Sabah (Paramananthan, 2000). The soil families in Sabah were defined using the older draft versions of the *FAO/Unesco Soil of The World Legend* (Acres *et al.*, 1975). Thirteen soil families having morphological, physical and chemical characteristic suitable for oil palm cultivation were selected. They are Apas, Bengawat, Buran, Inanam, Kelawat, Koyah, Kumansi, Lumisir, Lumpongan, Paliu, Pinianakan, Table and Tanjung Lipat. These soils have similar characteristics with those in Sarawak, namely Mudar, Bijat, Bedup, Merit, Lupar, Meluga, Tukau and Tarat Series.

The nutrients that are important for oil palm growth such as N available P, K and exchangeable Mg were analysed. The data was the averaged value of A and B horizon of soil pedon by adapting weighing factors as listed in each soil family. This method was used since the nutrient uptake activity is not limited to the upper part of soil only.

Each nutrient was evaluated according to their soil fertility status for oil palm plantation. The results show that nitrogen status varies substantially for each soil families. The moderate N level was found mainly from parent material of mudstone, basic igneous rocks and sub-recent alluvium such as Lumpongan, Apas, Piniakan and Paliu families. Soil families derived from recent alluvium such as Bengawat, Buran, Koyah and Inanam have high N content. Soil from sandstone/ mudstone and terrace alluvium such as Kumansi, Tanjung Lipat and Lumisir family were low in N content.

Sabah soils from Koyah, Paliu, Kumansi, Lumpongan, Apas, Tanjung Lipat and Piniakan families were low in available P. The high P content was found in Bengawat families which were mainly located at floodplains area. This high P resulted from the effect of the flood and erosion material from upland area.

The content of K in soil was low mainly in sandstone and ultrabasic soils such as in Tanjung Lipat, Lumisir, Kumansi, Kelawat, Paliu, Piniakan, Apas and Table families. The soil families of Bengawat, Buran and Lumpongan are high in K. The high K content was due to accumulation of sediments especially in Bengawat family.

The Mg's level in soil were high in most parts of Sabah. Soil families which were derived of sub-group mixed tuffs and sedimentary rocks obviously contained low K but high in Mg [> 0.5 cmol (+) kg^{-1}] such as Lumpongan, Bengawat and Buran. Therefore, the Mg requirements for oil palm in Sabah soils is considered minimal. However, the Mg uptake is low if calcium (Ca) and K are high at the soil exchange site. Soil families such as Kelawat, Paliu, Tanjung Lipat were low in Mg. Details of the average nutrients concentration from A and B horizons are as shown in *Table 1*.

General Sabah Soil Classification and Correlation

The Sabah soil classification was obtained from Department of Agriculture, Sabah (Elizabeth *et al.*, 2009). The distribution of soil families in Sabah were based according to the Soil Association Map and its legends (*Table 2)*. In Sabah soil classification, there are several soil families classified under one soil association, for an example Apas families is also allocated under Apas and Kenned Bay soil associations. The soil units/associations were used to derive oil palm site yield potential, therefore further analysis of soil chemical properties based on various soil families within soil unit/associations were needed to define the appropriate fertiliser requirement for a specific soil families. To be more precise, individual soil chemicals analysis methods were used to determine the best nutrient ratio for oil palm growth. This procedure was used to derive the balanced fertiliser ratio.

Soil Fertility Classification and Score

Classification of soil fertility and soil score for each soil families were based on data tabulated in *Table 3*. The soil fertility score ranges from 0.5 to 1.5 and score of 1 or soil fertility classification at moderate is a guide that there is no additional neither reduction on fertiliser requirement. The soil fertility scores and oil palm nutrient balance were used to derive nutrient ratio at average yield of 28 to 30 t FFB ha^{-1} yr^{-1}. The results showed that about 38%, 84.6% and 69.2% of these soils were classified as low in N, P and K respectively as shown in *Table 4*. This implied that high amount of P and K for balanced nutrient requirement in compound fertiliser is remarkably needed.

Nutrient Balance of Oil Palm (9 to 12 years old)

To formulate balanced nutrient ratio, the annual nutrient requirements of oil palm were calculated based on data in *Table 5*. The data was derived from fertiliser trials, with regards to the amount of nutrients removed by FFB, immobilised in the trunk and roots or lost through erosion, runoff and leaching (Tarmizi and Tayeb, 2006). The FFB yield was based on 30 t FFB ha^{-1} and palms were fertilised with 4.2 kg sulphate of ammonia (SOA), 3 kg phosphate rock (PR) and 3.5 kg potassium

TABLE 1. THE AVERAGE OF SOILS NUTRIENTS CONCENTRATION FROM A AND B HORIZONS

Sabah soil families	Average nutrients concentration at A and B horizons			
	N	P	K	Mg
Apas (Tarat)	0.15	1.99	0.09	0.34
Bangawat (Mudar)	0.25	36.58	1.03	11.19
Buran	0.24	16.95	0.68	13.13
Inanam (Meluga)	0.12	5.82	0.24	1.79
Kelawat (Tukau)	0.08	11.00	0.22	0.10
Koyah (Bijat)	0.21	2.73	0.17	4.12
Kumansi (Merit)	0.11	3.35	0.11	0.72
Lumisir	0.11	9.55	0.10	0.28
Lumpongan	0.18	7.70	0.57	10.40
Paliu (Lupar)	0.14	8.83	0.14	0.12
Piniakan	0.17	1.70	0.05	3.08
Table	0.24	122.33	0.19	0.93
Tg. Lipat	0.07	8.63	0.07	0.13

Note: Sarawak soils series in parenthesis: Mg - magnesium; N - nitrogen; P - phosphorus; K - potassium.

TABLE 2. THE 51 KEYS LEGEND OF SABAH SOIL ASSOCIATION MAP

Key	Association	Land from	Parent materials	Main soil units
1	Weston	Tidal swamps	Sulphidic alluvium, sulphidic peat and alluvium	Thionic Fluvisiol; Dystric Histosol; Thionic Gleysol
2	Usukan	Beaches	Calcareous alluvium	Calcaric Regosol; humic Gleysol
3	Tanjong Aru	Beaches	Alluvium	Dystric and Eutric Regosols; Humic, Dystric and Eutric Gleysols; Gleyic Podzol
4	Tuaran	Meander Belts	Alluvium	Eutric Fluvisol; Gleyic, Dystric and Eutric Cambisols; Humic, dystric and Euric Gleysols
5	Kinabatangan	Floodplains	Alluvium	Gleyic Acrisol; Gleyic Luvisol; Humic, Dystric and Eutric Gleysols
6	Sapi	Swamps	Alluvium and peat	Humic, Dystric and Eutric Gleysols; Dystric Histosol
7	Klias	Swamps	Peat and alluvium	Dystric Histosol; Humic Gleysol
8	Binalik	Valley floors and terraces	Alluvium derived from ultrabasic rocks	Orthic Ferralsol; Gleyic, Ferric and Orthic Luvisols; Ferric and Orthic Acrisols
9	Karamuk	Valley floors and terraces	Alluvium and alluvium derived from basic/ ultrabasic rock	Gleyic,Chromic and Orthic Luvisols; Gleyic and Eutric Cambisols; Eutric Fluvisol
10	Labau	Valley floors and terraces	Alluvium	Gleyic and Dystric Cambisols; Dystric and Eutric Fluvisols; Gleyic and Orthic Acrisols
11	Binkor	Terraces	Alluvium	Dystric and Eutric Gleysols; Gleyic Luvisol
12	Brantian	Terraces	Alluvium	Orthic, Ferric and Gleyic Acrisols; Gleyic Podzol
13	Kepayan	Terraces	Alluvium	Gleyic Podzol; Gleyic Acrisol
14	Sook	Terraces	Alluvium	Gleyic and Orthic Acrisols; Gleyic Podzol; Dystric Gleysol
15	Sipitang	Swamps	Peat and alluvium	Dystric Histosol; Gleyic Podzol
16	Sinarum	Dissected terraces; slopes 15º-25º	Alluvium, sandstone and mudstone	Orthic Acrisol; Dystric Gleysol; Dystric Cambisol
17	Tungku	Terraces	Calcareous alluvium	Chromic and Gleyic Luvisols
18	Pinosuk	Plateau with gently undulating surface and dissected terraces with slopes up to 25º	Colluvium, sandstone and mudstone	Gleyic Podzol; Gleyic and Orthic Acrisols; Humic and Dystric Gleysols
19	Tawai	Plateau with gently undulating surface	Ironstone and alluvium derived from ultrabasic	Dystric Histosol; Dystri c Gleysol; Dystric Cambisol
20	Tapang	Low hills (slopes 0º-15º), terraces and valley floors	Basic igneous rocks and alluvium	Xanthic Ferralsol; Orthic Acisol; Orthic Luvisol; Eutric Gleysol
21	Semporna	Very low hills: slopes 0º-15º	Limestone	Calcic and Chromic Luvisols;Rendzina
22	Lungmanis	Very low (slopes 0º-15º) and valley floors	Mudstone and alluvium	Gleyic, Ferric and Orthic Acrisols; Gleyic, Ferric Chromic and Orthic Luvisols
23	Table	Dissected plateaus with flat to gently undulating surfaces	Basic igneous rocks	Xanthic and Orthic Ferralsols
24	Orchid Plateau	Plateau of low hills; slopes 15º-25º	Basic and intermediate igneous rocks	Orthic Acrisol; Orthic and Chromic Luvisols
25	Silabukan	Low hills and minor valley floors: slopes 0º-15º	Mudstone and alluvium	Gleyic, Ferric and Orthic Acrisols; Gleyic, Ferric, Chromic and Orthic Luvisols
26	Rumidi	Low hills and minor valley floors: slopes 0º-15º	Mudstone, sandstone and miscellaneous rocks	Gleyic, Ferric and Orthic Acrisols; Gleyic, Ferric, Chromic and Orthic Luvisols

TABLE 2. THE 51 KEYS LEGEND OF SABAH SOIL ASSOCIATION MAP (continue)

Key	Association	Land from	Parent materials	Main soil units
27	Sipit	Low hills: slopes 0º-15°	Mudstone, sandstone and miscellaneous rocks	Ferric and Orthic Acrisols; Orthic Luvisol
28	Apas	Moderate hills : slopes 15º-25º	Intermediate and acid igneous rock	Rhodic Ferralsol; Orthic Acrisol; Eutric Cambisol
29	Kalabakan	Moderate hills: slopes 0º-20º	Mudstone and sandstone	Ferric and Orthic Acrisols; Ferric, Chromic and Orthic luvisols
30	Mawing	Moderate hills: slopes >25	Mudstone and sandstone	Orthic Acrisol; Dystric Cambisol
31	Dalit	Moderate hills and minor valley floors: slopes 0º-20º	Sandstone, mudstone and alluvium	Orthic, Ferric and Gleyic Acrisols
32	Tengah Nipah	Moderate hills and minor valley floors: slopes 0º-20º	Sandstone, mudstone and alluvium	Ferric, Orthic and Gleyic Acrisols
33	Kretam	Moderate hills: slopes 0º-20º	Mudstone, sandstone and miscellaneous rocks	Ferric and Orthic Acrisolt; Ferric, Chromic and Orthic Luvisols
34	Beruang	High hills: slopes 15º-25º	Basic igneous rocks	Ferric Acrisol; Orthic Luvisol
35	Dagat	Moderate hills: slopes 10º-20º	Tuffaceous rock, mudstone and sandstone	Chromic and Orthic Luvisols; Orthic Acrisol
36	Kennedy Bay	High hills: slopes >25º	Sandstone, mudstone and Igneous rock	Ferric Acrisol; Chromic and Orthic Luvisols; Dystric and Eutric Cambisols
37	Tiger	Very high hills; slopes >25º	Basic igneous rocks	Chromic and Eutric Cambisols
38	Gomantong	Very high hills; slopes >25º	Limestone	Calcic Luvisol; Rendzina
39	Lokan	Very high hills; slopes >25º	Sandstone and mudstone	Orthic Acrisol; Dystric Cambisol
40	Bang	Very high hills; slopes 15º-25º	Mudstone, sandstone and miscellaneous rocks	Orthic Acrisol; Dystric Cambisol
41	Bidu Bidu	Mountains and hills	Ultrabasic igneous rocks	Rhodic and orthic Ferralsols; Eutric Cambisol; Chromic and Orthic Luvisols; Lithosol
42	Mentapok	Mountains	Basic and intermediate igneous rocks	Chromoc and Orthic Luvisols; Eutric Cambisol; Lithosol
43	Tinagat	Mountains	Basic and intermediate igneous rock	Eutric Cambisol; Lithosol; Ferric Luvisol
44	Malubok	Mountains	Igneous rock, sandstone, mudstone and chert	As for Association 41,42 and 47 with chromic Cambisols and Lithosols on chert
45	Wullersdorf	Mountains	Intermediate and acid igneous rocks	Eutric Cambisol; Lithosol
46	Gumpal	Mountains and hills	Mudstone, sandstone and miscellaneous rocks	Orthic Acrisol; Orthic Luvisol; Dystric and Eutric Cambisols; Lithosol
47	Crocker	Mountains	Sandstone and mudstone	Orthic Acrisol; Chromic and Dystric Cambisols Lithosol
48	Maliau	Mountain cuestas	Sandstone and mudstone	Orthic Acrisol; Dystric Cambisol; Gleyic Podzol;
49	Serudung	Dipslopes of mountains cuestas	Sandstone	Gleyic Podzol; Orthic Acrisol
50	Trusmadi	Mountains above 12 000 m (4000 ft) a.s.l	Sandstone and mudstone	Gleyic and Orthic Acrisols; Gleyic Podzol; Humic Gleysol; Dystric Histosol; Lithosol
51	Kinabalu	Mountains above 24 000 m (8000 ft) a.s.l	Acid igneous rocks	Humic Cambisol; Dystric Histosol; Lithosol

TABLE 3. SOIL FERTILITY CLASSIFICATION AND SCORE FOR NITROGEN (N), PHOSPHORUS (P), POTASSIUM (K) AND MAGNESIUM (Mg) IN OIL PALM

Soil nutrients	+Soil Fertility Classification	Very low	Low	Moderate	High	Very high
	*Soil Score	1.50	1.25	1.00	0.75	0.50
Total N (%)		0.08	0.12	0.15	0.25	>0.25
Avai. P (cmol(+)kg^{-1})		<8	15.00	20.00	25.00	>25
Exch. K (cmol(+)kg^{-1})		<0.08	0.20	0.25	0.30	>0.3
Exch. Mg (cmol(+)kg^{-1})		<0.08	0.20	0.25	0.30	>0.3

Avai = available, Exch = exchangeable; After: +Goh and Rolf (2003). *Adiwiganda (2002).

TABLE 4. NUTRIENTS CLASSIFICATION IN RELATION TO OIL PALM REQUIREMENT

Sabah soil families	Nutrients classification			
	N	P	K	Mg
Apas (Tarat)	M	VL	VL	VH
Bangawat (Mudar)	H	VH	VH	VH
Buran	H	L	VH	VH
Inanam (Meluga)	L	VL	M	VH
Kelawat (Tukau)	VL	L	L	VL
Koyah (Bijat)	H	VL	L	VH
Kumansi (Merit)	L	VL	VL	H
Lumisir	L	L	VL	M
Lumpongan	M	VL	VH	VH
Paliu (Lupar)	M	VL	L	VL
Piniakan	M	VL	VL	VH
Table	H	H	L	VH
Tg. Lipat	VL	VL	VL	L

Note: Sarawak soils series in parenthesis; VL = very low, L = low, M = moderate, H = high, VH = very high.

chloride (MOP) $palm^{-1}$ yr^{-1}. Derivation of nutrient ratio for balanced fertiliser formulation for Sabah and Sarawak soils should not deviate very much from the estimated nutrient requirement or not above the maximum rate of 4.2 kg SOA, 3 kg PR and 3.5 kg MOP $palm^{-1}$ yr^{-1}.

CALCULATION FOR NUTRIENT RATIO

The nutrient ratio is determined based on the following steps:

1st : Analyse data on the soil nutrient status.
2nd: Calculate the total nutrient demand of each palm (stand per ha = 136) based on 30 t FFB.
3rd: The results from step 1 was multiplied with the soil indices (SI), where the SI score from 0.5 to 1.5 and SI of 1 or soil fertility classification ranked as moderate was a guide so that neither additional nor reduction of fertiliser.
4th: Calculate the Sabah FFB production and compared with 30 t FFB from the 2nd step.

5th: Define the nutrient formulation of compound fertiliser *(Appendices 1* to *13).*
6th: Calculate the fertiliser requirement per palm basis *(Appendices 1* to *13).*
7th: Check and balance (as shown in *Tables 7* and *8*).

The calculation of nutrient and fertiliser ratios for each soil families/series was based on the following equations:

Equation I:

Nutrient ratio = soil fertility score x nutrient balance (removed, immobilised and lost) x nutrient conversion (*e.g*: P to P_2O_5)

Equation II:

Fertiliser formulation = nutrient ratio x FFB yield x % total nutrient in compound fertiliser (*e.g*. 40%)

The summary of soils description, fertility characteristics and fertiliser ratio from 13 major soils favourable for oil palm cultivation in Sabah and correlated soils in Sarawak were presented individually as follows:

- *Apas families (Appendix 1)*
- *Bengawat families (Appendix 2)*
- *Buran families (Appendix 3)*
- *Inanam families (Appendix 4)*
- *Kelawat families (Appendix 5)*
- *Koyah families (Appendix 6)*
- *Kumansi families (Appendix 7)*
- *Lumisir families (Appendix 8)*
- *Lumpongan families (Appendix 9)*
- *Paliu families (Appendix 10)*
- *Pinianakan families (Appendix 11)*
- *Table families (Appendix 12) and*
- *Tanjung Lipat families (Appendix 13)*

THE PROPOSED FERTILISER NUTRIENT RATIO

Based on nutrient ratio calculated at each soil families and at maximum total nutrient contents of 40%, the nutrients were ranged between 9% to 16%, 2% to 6%, 15% to 27% and 1% to 4% for N: P_2O_5: K_2O and MgO respectively. The average proportion of this proposed compound is 12:3:23:2 for N:P_2O_5:K_2O:MgO (*Table 6*). The rate of 1 kg of this compound is equivalent to 0.57 kg of SOA, 0.10 kg of RP, 0.37 kg of MOP and 0.07 kg of kieserite. Based on the calculation, the minimum dosage of this proposed fertiliser in mature palm is 8.5 kg palm^{-1} yr^{-1}. As for nutrient equivalent, 8.5 kg of this fertiliser is equivalent to 1.06 kg N, 0.11 kg P, 1.62 kg K and 0.103 kg Mg. As shown in *Table 5*, N, P, K and Mg fertilisers requirement for mature palm were 129.4 kg N ha^{-1} yr^{-1}, 12.9 kg P ha^{-1} yr^{-1}, 210.5 kg K ha^{-1} yr^{-1} and 22 kg Mg ha^{-1} yr^{-1} or equivalent to 0.95 kg N palm^{-1} yr^{-1}, 0.09 kg P palm^{-1} yr^{-1}, 1.55 kg K palm^{-1} yr^{-1} and 0.16 kg Mg palm^{-1} yr^{-1}. Therefore, 8.5 kg palm^{-1} yr^{-1} of the proposed compound fertiliser is sufficient for the mature oil palm.

The recommendation rate of 8.5 kg palm^{-1} yr^{-1} was reasonable to be applied for oil palm plantations planted in the wide range of soil fertility in Sabah. However, at 8.5 kg palm^{-1} yr^{-1}, the Mg applied is 0.06 kg palm^{-1} yr^{-1} which is less than the standard requirement. Any additional straight fertiliser input will be based on annual nutrient leaf analysis.

Alteration of the Fertiliser Ratio

The minor alteration of the N, P and K ratio was done to reduce the production cost and soil P fixation problem without compromising on the minimum nutrient ratio. Due to low available and high fixation of P by most of Sabah soil families especially from basaltic soils, therefore percentage of P_2O_5 should be increased up to 6%. Additional amount of P could increase the P availability at soil exchange site. As shown in *Table 6*, the minimum ratio of N, P, K and Mg is 9º, 2º, 16º and 1% respectively. Therefore, additional or reduction of the nutrients should not be much different from the estimated nutrient requirement. After taken into account of the fertiliser sources and their price, the final recommended formulation of the proposed compound fertiliser is 11:6:22:2:0.5 of N: P_2O_5:K_2O: MgO: B_2O_3 respectively, at 41.5% total maximum nutrient ratio. The reduction of 1% of N and K definitely will reduce the cost of production and fertiliser become more cost-effective. Surveys were done to evaluate the maximum total nutrient ratio of fertilisers available in the market. Result of the surveys showed that, from 13 different compound fertilisers available in the market and MPOB's formulation fertilisers, the total nutrients were ranged between 35% to 48% and 23.5% to 40.5%, respectively. Therefore, the formulation with 41.5% of the ratios is considered acceptable fertiliser's ratio in the market.

Check and Balance

Manual calculation was made to determine whether the amount of nutrient needed by the palm could be provided by the derived formulation of 11:6:22:2:0.5. The results were summarised according to palm age as shown in *Tables 7* and *8*. At the rate of 8.5 to 9 kg palm^{-1} yr^{-1} this fertiliser is equivalent to 0.94 – 0.99 kg N, 0.51 – 0.54 kg P_20_5, 1.87 – 0.18 kg K_20 0.17 – 0.18 kg MgO and 0.04 – 0.05 kg B_2O_5 kg palm^{-1}. Based on the above rate, the compound fertiliser is equivalent to 4.45 – 4.71 kg of SOA, 1.82 – 1.93 kg of RP, 3.12 – 3.30 kg of MOP, 0.63 – 0.67 kg of kieserite and 0.39 – 0.41 kg Borate palm^{-1} *(Table 8).* As shown by Tarmizi and Tayeb

TABLE 5. NUTRIENT BALANCE OF OIL PALM (9 to 12 years old)

Fertiliser requirement based on nutrients removed, immobilised and lost (kg ha^{-1} yr^{-1})					
A. Palm demand		**N**	**P**	**K**	**Mg**
Nutrient content in 30 t FFB ha^{-1}		97.6	10	105.4	18.2
Nutrient immobilised in trunk and roots		18.5	2.4	61.9	3.8
	Total	116.1	12.4	167.3	22
Fertiliser application* for 136 palms ha^{-1}		120	16.1	285.6	0
B. Environment demand					
Erosion losses and surface runoff losses (%)		8	1.6	15.3	7.6
Leaching losses		3	1.5	2.9	15.5
Expected losses (%)		11	3.1	18.2	23.1
Expected losses (kg ha^{-1})		13.2	0.5	52	0
Nutrient requirement based on nutrients removed, immobilised and lost (kg ha^{-1} yr^{-1})					
Mature Palm (9 -12 year old)		129.4	12.9	219.3	22

Notes: *4.2 kg Sulphate of ammonia (SOA), 3 kg rock phosphate (RP) and 3.5 kg potassium chloride (MOP) $palm^{-1}$ yr^{-1}.
Source: Tarmizi and Tayeb (2006).

TABLE 6. THE SUMMARY AND AVERAGE OF FERTILISER RATIO FROM 13 MAJOR SOIL FAMILIES PLANTED WITH OIL PALM IN SABAH

Soil family (Sabah)	Close correlated with Sarawak soils	N	P_2O_5	K_2O	MgO
Bengawat	Mudar Series	15.11	2.3	19.75	2.84
Koyah	Bijat Series	8.14	3.72	26.61	1.53
Tg. Lipat	Bedup Series	11.53	2.63	22.59	3.25
Kumansi	Merit Series	10.54	2.89	24.79	1.78
Paliu	Lupar Series	9.49	3.25	23.25	4.01
Lumisir	No equivalent	11.98	2.28	23.49	2.25
Inanam	Meluga Series	13.54	3.71	21.23	1.53
Kelawat	Tukau Series	12.88	2.45	21.04	3.63
Lumpongan	No equivalent	16.24	5.56	15.91	2.29
Pinianakan	No equivalent	9.04	3.1	26.59	1.27
Buran	No equivalent	13.91	5.3	18.18	2.61
Table	No equivalent	8.54	1.95	27.9	1.61
Apas	Tarat Series	9.04	3.1	26.59	1.27
Average ratio		12	3	23	2

Note: N - Nitrogen.
P_2O_5 - Rock phosphate.
K_2O - Murate of potash.
MgO - German kieserite.

TABLE 7. RECOMMENDATION OF COMPOUND FERTILISER (11:6:22:2:0.5) APPLICATION FOR OIL PALM AT VARIOUS PALM AGES

Palm age	Fertiliser (11:6:22:2:0.5) (kg palm^{-1} yr^{-1})	Nutrient (kg palm^{-1})				
		N	P_2O_5	K_2O	MgO	B_2O_5
1	4	0.44	0.24	0.88	0.08	0.02
2	6	0.66	0.36	1.32	0.12	0.03
3	6.5	0.72	0.39	1.43	0.13	0.03
4	7.5	0.83	0.45	1.65	0.15	0.04
5	8	0.88	0.48	1.76	0.16	0.04
6 to 20	8.5 - 9.0	0.94 - 0.99	0.51 – 0.54	1.87 - 1.98	0.17 - 0.18	0.04 - 0.05
21 to 23	8	0.88	0.4	1.76	0.16	0.04
24	5	0.55	0.25	1.1	0.1	0.03
25	0	0	0	0	0	0

Note: The above rates serves as a general guide, depending on palm age, soil nutrient status, weather condition and management practices. N - nitrogen. P_2O_5. MgO.

N - Nitrogen.
P_2O_5 - Rock phosphate.
MgO - German kieserite
K_2O - Murate of potash.
B_2O_5 - Borate -48

TABLE 8. THE EQUIVALENT OF COMPOUND FERTILISER (11:6:22:2:0.5) TO STRAIGHT FERTILISERS APPLICATION FOR OIL PALM AT VARIOUS PALM AGES

Palm age	Fertiliser (11:6:22:2:0.5) (kg palm^{-1} yr^{-1})	Equivalent to straight fertiliser (kg palm^{-1})				
		SOA	RP	MOP	KIES	BORATE
1	4	2.10	0.86	1.47	0.30	0.18
2	6	3.14	1.29	2.20	0.44	0.27
3	6.5	3.40	1.39	2.38	0.48	0.30
4	7.5	3.93	1.61	2.75	0.56	0.34
5	8	4.19	1.71	2.93	0.59	0.36
6 to 20	8.5 - 9.0	4.45 - 4.71	1.82 – 1.93	3.12 - 3.30	0.63 - 0.67	0.39 - 0.41
21 to 23	8	4.19	1.33	2.93	0.59	0.36
24	5	2.62	0.83	1.83	0.37	0.23
25	0	0		0	0	0

Note: The above rates serves as a general guide, depending on palm age, soil nutrient status, weather condition and management practices.

SOA - Sulphate of ammonia.
MOP - Potassium chloride.
KIES - Kieserite.
RP - Rock phosphate.

(2006), the maximum rate of 4.2 kg SOA , 3 kg PR and 3.5 kg MOP palm^{-1} yr^{-1} were required to sustain a 30 t FFB ha^{-1}. Based on the calculation, the final formulation of N:P:K:Mg:B ratio at 11:6:22:2:0.5 clearly meet the requirement of oil palm nutrients for Sabah and Sarawak mineral soils. In addition the recommendation rate of 8.5 to 9.0 kg palm^{-1} yr^{-1} was reasonable to be applied in mature oil palm.

SELECTION OF FERTILISER SOURCES FOR THE COMPOUND

The compound fertiliser will be produced in pellet-form containing a total of 86% chemical fertiliser, 9% organic matter for pellet binder and 5% of soil conditioner to increase efficiency of nutrient uptake.

Nitrogen

Urea is chosen as a source of N nutrient because of its high concentration of N (46%), less detrimental to the environment compared to more leachable nitrate based and the cheapest source of N in term of unit price of N. The volatilisation loss of ammonia can be minimised by incorporating MOP and Mg in compound fertiliser.

Phosphorus (P)

Phosphate rock (preferably JRP) is selected with P content ranges from 28% to 30% P_2O_5

Potassium

Murate of potash (60% K_2O)

Magnesium

German kieserite (27% MgO)

Boron

Borate-48 (48% B_2O_3)

Organic Matter (total 9%)

Organic waste from palm oil mill (80% mill effluent and 20% decanter cake). Integrating inorganic and organic fertilisers could increase the efficiency of nutrient uptake by the crops and enhance the long-term nutrient retention in the soil to improve the soil quality.

Soil Conditioner (total 5%)

Preferably natural mineral product known as azomite which contains broad spectrum of active minerals and trace minerals which will be react as combination of trace element inside plant. As an example, in plants iron and mg are associated in chlorophyll formation. Azomite is a natural trace element compound that typically contains more than 70 minerals and more than 60% of silica oxide (SiO_2). It is chemical-free and internationally certified for organic production. Plants applied with Azomite have a healthier vascular system, making the transport of nutrients and assimilates more efficient. It is common practice today to focus on the supply of major nutrients (N-P-K) to oil palm plantations. While the benefits of boron have been clearly established, the application of other trace elements is often neglected. This practice stands in contrast to the plant's physiological requirement of more than 20 different elements. Azomite is used to improve the mineral balance of the soil. With continuous planting, soils are likely to be depleted of trace elements which are needed for optimum oil palm growth. After two or three generations of oil palm planting, the need to replenish the soil with a complete trace element fertiliser is required to avoid yield reduction and disease incidences.

CONCLUSION

The formulation of compound fertiliser based on soil fertility of Sabah soils taking into account that the nutrient demands was derived comprehensively. The final formulation is (11:6: 22: 2: 0.5 of N: P_2O_5: K_2O: MgO: B_2O_3) respectively at 41.5% of total nutrient ratio. These balanced fertiliser ratio is suitable for oil palm planted in various soil types in Sabah. The fertiliser contains 86% chemical fertiliser, 9% organic matter for pellet binder and 5% of supreme soil conditioner to increase efficiency of nutrient uptake especially for soil with low in organic matter such as on terraced area, lateritic, sandy and loamy soils. The incorporation of 5.0% Azomite with high SiO_2 into the well balanced formula ensures that the oil palm is adequately supplied with the major nutrients as well as the important trace elements necessary for healthy oil palm growth and better yield. Recycling of organic matter from palm waste will reduce the cost of palm oil production and make significant contribution for more sustainable oil palm industry.

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Appendix 1

APAS FAMILY (Ferralsol)

Soil Classification
FAO/UNESCO LEGEND: Rhodic Ferralsol
USDA Taxonomy: Typic Hapludox (clyey, very fine, oxidic, isohyperthermic)

Parents Material: Basic Igneous Rocks (Basalt)

Distribution *(Soil Association key legend in parenthesis)*
Apas (28) and Kennedy Bay (36) Soil Associations.

Soil Fertility Characteristics

Major nutrient parameters	Nutrients concentration (average of A and B horizons)	Nutrients classification in relation to oil palm requirements	Soil fertility score in relation to nutrients classification
Nitrogen (%)	0.15	Moderate	1.00
Available phosphorous (mg kg^{-1})	1.99	Very low	1.50
Exchangeable K (cmol kg^{-1})	0.09	Very low	1.50
Exchangeable Mg (cmol kg^{-1})	0.34	Very high	0.50

Fertiliser Ratio

i. Compound fertiliser ratio (%) for the average FFB yield between 28 to 30 t ha^{-1} yr^{-1}

N	P_2O_5	K_2O	MgO	Total nutrient (%)
0.95	0.33	2.80	0.13	4.21

ii. Compound fertiliser at 40% of maximum nutrient ratio

N	P_2O_5	K_2O	MgO	Total nutrient (%)
9.04	3.10	26.59	1.27	40

Appendix 2

BENGAWAT FAMILY (Gleysols)

Soil Classification
FAO/UNESCO LEGEND: Eutric Gleysols
USDA Taxonomy: Eutric/Aeric Endoaquepts/Endoaquents

Parents Material: Alluvium

Distribution *(Soil Association key legend in parenthesis)*
Common in Kinabatangan (5), Tuaran (4), Labau (10), Sapi (6), Binkor (11), Sinarun (16), Brantian (12), Kepayan (13), Dalit (31), Tanjung Aru (3) and Sepitang (15) Soil Associations.

Soil Fertility Characteristics

Major nutrient parameters	Nutrients concentration (average of A and B horizons)	Nutrients classification in relation to oil palm requirements	Soil fertility score in relation to nutrients classification
Nitrogen (%)	0.25	high	0.75
Available phosphorous (mg kg^{-1})	36.58	very high	0.50
Exchangeable K (cmol kg^{-1})	1.03	very high	0.50
Exchangeable Mg (cmol kg^{-1})	11.19	very high	0.50

Fertiliser Ratio

i. Compound fertiliser ratio (%) for the average FFB yield between 28 to 30 t ha^{-1} yr^{-1}

N	P_2O_5	K_2O	MgO	Total nutrient (%)
0.71	0.11	0.93	0.13	1.89

ii. Compound fertiliser at 40% of maximum nutrient ratio

N	P_2O_5	K_2O	MgO	Total nutrient (%)
15.11	2.30	19.75	2.84	40

Appendix 3

BURAN FAMILY (Luvisol)

Soil Classification
FAO/UNESCO LEGEND: Gleyic Luvisol
USDA Taxonomy: Typic Endoaqualfs

Parents Material: Terrace alluvium

Distribution *(Soil Association key legend in parenthesis)*
Kinabatangan (5), Sapi (6), Tuaran (4), Karamuak (9), Lungmanis (22), Silabukan (25), Rumidi (26), Kalabakan (29) and Tengah Nipah (32) Soil Associations.

Soil Fertility Characteristics

Major nutrient parameters	Nutrients concentration (average of A and B horizons)	Nutrients classification in relation to oil palm requirements	Soil fertility score in relation to nutrients classification
Nitrogen (%)	0.24	High	0.75
Available phosphorous (mg kg^{-1})	16.95	Low	1.25
Exchangeable K (cmol kg^{-1})	0.68	Very high	0.50
Exchangeable Mg (cmol kg^{-1})	13.13	Very high	0.50

Fertiliser Ratio

i. Compound fertiliser ratio (%) for the average FFB yield between 28 to 30 t ha^{-1} yr^{-1}

N	P_2O_5	K_2O	MgO	Total nutrient (%)
0.71	0.27	0.93	0.13	2.05

ii. Compound fertiliser at 40% of maximum nutrient ratio

N	P_2O_5	K_2O	MgO	Total nutrient (%)
13.91	5.30	18.18	2.61	40

INANAM FAMILY (Acrisols)

Soil Classification
FAO/UNESCO LEGEND: Gleyic Acrisols
USDA Taxonomy: Typic Kandiudult (imperfect drained), Typic/Aeric Kandiaquult (poorly drained)

Parents Material: Mixed riverine/brackish water deposit

Distribution *(Soil Association key legend in parenthesis)*
Dominant in Kinabatangan (5), Sook (14) and Lungmanis (22) Soil Associations;
Common in Labau (10), Brantian (12), Kepayan (13) and Dalit (31) Soil Associations

Soil Fertility Characteristics

Major nutrient parameters	Nutrients concentration (average of A and B horizons)	Nutrients classification in relation to oil palm requirements	Soil fertility score in relation to nutrients classification
Nitrogen (%)	0.12	low	1.25
Available phosphorous (mg kg^{-1})	5.82	very low	1.50
Exchangeable K (cmol kg^{-1})	0.24	moderate	1.00
Exchangeable Mg (cmol kg^{-1})	1.79	very high	0.50

Fertiliser Ratio

i. Compound fertiliser ratio (%) for the average FFB yield between 28 to 30 t ha^{-1} yr^{-1}

N	P_2O_5	K_2O	MgO	Total nutrient (%)
1.19	0.33	1.87	0.13	3.51

ii. Compound fertiliser at 40% of maximum nutrient ratio

N	P_2O_5	K_2O	MgO	Total nutrient (%)
13.54	3.71	21.23	1.53	40

Appendix 5

KELAWAT FAMILY (Cambisols)

Soil Classification
FAO/UNESCO LEGEND: Dystric Cambisols
USDA Taxonomy: Typic Dystrudepts

Parents Material: Colluvium/alluvium

Distribution *(Soil Association key legend in parenthesis)*
Common in Kinabatangan (5), Tuaran (4), Labau (10), Binkor (11) and Sook (14) Soil Associations

Soil Fertility Characteristics

Major nutrient parameters	Nutrients concentration (average of A and B horizons)	Nutrients classification in relation to oil palm requirements	Soil fertility score in relation to nutrients classification
Nitrogen (%)	0.08	Very low	1.50
Available phosphorous (mg kg^{-1})	11.00	low	1.25
Exchangeable K (cmol kg^{-1})	0.22	low	1.25
Exchangeable Mg (cmol kg^{-1})	0.10	very low	1.50

Fertiliser Ratio

i. Compound fertiliser ratio (%) for the average FFB yield between 28 to 30 t ha^{-1} yr^{-1}

N	P_2O_5	K_2O	MgO	Total nutrient (%)
1.43	0.27	2.33	0.40	4.43

ii. Compound fertiliser at 40% of maximum nutrient ratio

N	P_2O_5	K_2O	MgO	Total nutrient (%)
12.88	2.45	21.04	3.63	40

Appendix 6

KOYAH FAMILY (Gleysols)

Soil Classification
FAO/UNESCO LEGEND: Distric Gleysols
USDA Taxonomy: Typic Endoaquepts/Endoaquents

Parents Material: Recent riverine alluvium

Distribution *(Soil Association key legend in parenthesis)*
Common in Kinabatangan (5), Tuaran (4), Labau (10), Sapi (6), Binkor (11), Sinarun (16), Brantian (12), Kepayan (13), Dalit (31), Tanjung Aru (3) and Sepitang (15) Soil Associations.

Soil Fertility Characteristics

Major nutrient parameters	Nutrients concentration (average of A and B horizons)	Nutrients classification in relation to oil palm requirements	Soil fertility score in relation to nutrients classification
Nitrogen (%)	0.21	high	0.75
Available phosphorous (mg kg^{-1})	2.73	very low	1.50
Exchangeable K (cmol kg^{-1})	0.17	low	1.25
Exchangeable Mg (cmol kg^{-1})	4.12	very high	0.50

Fertiliser Ratio

i. Compound fertiliser ratio (%) for the average FFB yield between 28 to 30 t ha^{-1} yr^{-1}

N	P_2O_5	K_2O	MgO	Total nutrient (%)
0.71	0.33	2.33	0.13	3.51

ii. Compound fertiliser at 40% of maximum nutrient ratio

N	P_2O_5	K_2O	MgO	Total nutrient (%)
8.14	3.72	26.61	1.53	40

Appendix 7

KUMANSI FAMILY (Acrisols)

Soil Classification
FAO/UNESCO LEGEND: Haplic Acrisols
USDA Taxonomy: Typic Paleudults

Parents Material: Sandstone/mudstone

Distribution *(Soil Association key legend in parenthesis)*
Dominant in Kalabakan (29) Soil Associations;
Common in), Silabukan (25), Lungmanis (22), Rumidi (26), Trusmadi (50), Dagat (35), Mawing (30), and Croker (47) Soil Associations

Soil Fertility Characteristics

Major nutrient parameters	Nutrients concentration (average of A and B horizons)	Nutrients classification in relation to oil palm requirements	Soil fertility score in relation to nutrients classification
Nitrogen (%)	0.11	low	1.25
Available phosphorous (mg kg^{-1})	3.35	very low	1.50
Exchangeable K (cmol kg^{-1})	0.11	very low	1.50
Exchangeable Mg (cmol kg^{-1})	0.72	high	0.75

Fertiliser Ratio

i. Compound fertiliser ratio (%) for the average FFB yield between 28 to 30 t ha^{-1} yr^{-1}

N	P_2O_5	K_2O	MgO	Total nutrient (%)
1.19	0.33	2.80	0.20	4.51

ii. Compound fertiliser at 40% of maximum nutrient ratio

N	P_2O_5	K_2O	MgO	Total nutrient (%)
10.54	2.89	24.79	1.78	40

Appendix 8

LUMISIR FAMILY (Acrisols)

Soil Classification
FAO/UNESCO LEGEND: Ferric Acrisols
USDA Taxonomy: Plinthic Paleudult

Parents Material: Terrace alluvium

Distribution *(Soil Association key legend in parenthesis)*
Dominant in Brantian (12) Soil Associations;
Common in Sook (14), Labau (10) and Karamuak (9) Soil Associations

Soil Fertility Characteristics

Major nutrient parameters	Nutrients concentration (average of A and B horizons)	Nutrients classification in relation to oil palm requirements	Soil fertility score in relation to nutrients classification
Nitrogen (%)	0.11	Very low	1.50
Available phosphorous (mg kg^{-1})	9.55	low	1.25
Exchangeable K (cmol kg^{-1})	0.10	very low	1.50
Exchangeable Mg (cmol kg^{-1})	0.28	moderate	1.00

Fertiliser Ratio

i. Compound fertiliser ratio (%) for the average FFB yield between 28 to 30 t ha^{-1} yr^{-1}

N	P_2O_5	K_2O	MgO	Total nutrient (%)
1.43	0.27	2.80	0.27	4.76

ii. Compound fertiliser at 40% of maximum nutrient ratio

N	P_2O_5	K_2O	MgO	Total nutrient (%)
11.98	2.28	23.49	2.25	40

Appendix 9

LUMPONGAN FAMILY (Luvisols)

Soil Classification
FAO/UNESCO LEGEND: Orthic Luvisols
USDA Taxonomy: Lithic Hapludalfs

Parents Material: Tuffaceous mudstone

Distribution *(Soil Association key legend in parenthesis)*
Common in Lungmanis (22), Silabukan (25) and Rumidi (26) Soil Associations.

Soil Fertility Characteristics

Major nutrient parameters	Nutrients concentration (average of A and B horizons)	Nutrients classification in relation to oil palm requirements	Soil fertility score in relation to nutrients classification
Nitrogen (%)	0.18	moderate	1.00
Available phosphorous (mg kg^{-1})	7.70	very low	1.50
Exchangeable K (cmol kg^{-1})	0.57	very high	0.50
Exchangeable Mg (cmol kg^{-1})	10.40	very high	0.50

Fertiliser Ratio

i. Compound fertiliser ratio (%) for the average FFB yield between 28 to 30 t ha^{-1} yr^{-1}

N	P_2O_5	K_2O	MgO	Total nutrient (%)
0.95	0.33	0.93	0.13	2.34

ii. Compound fertiliser at 40% of maximum nutrient ratio

N	P_2O_5	K_2O	MgO	Total nutrient (%)
16.24	5.56	15.91	2.29	40

Appendix 10

PALIU FAMILY (Acrisols)

Soil Classification
FAO/UNESCO LEGEND: Haplic Acrisols
USDA Taxonomy: Typic Kandiudult

Parents Material: Sub-recent alluvium/colluvium

Distribution *(Soil Association key legend in parenthesis)*
Dominant in Brantian (12) Soil Associations;
Common in Labau (10), Sinarun ((16), Bingkor (11), Karamuak (9), and Sook (14) Soil Associations

Soil Fertility Characteristics

Major nutrient parameters	Nutrients concentration (average of A and B horizons)	Nutrients classification in relation to oil palm requirements	Soil fertility score in relation to nutrients classification
Nitrogen (%)	0.14	moderate	1.00
Available phosphorous (mg kg^{-1})	8.83	very low	1.50
Exchangeable K (cmol kg^{-1})	0.14	low	1.25
Exchangeable Mg (cmol kg^{-1})	0.12	very low	1.50

Fertiliser Ratio

i. Compound fertiliser ratio (%) for the average FFB yield between 28 to 30 t ha^{-1} yr^{-1}

N	P_2O_5	K_2O	MgO	Total nutrient (%)
0.95	0.33	2.33	0.40	4.01

ii. Compound fertiliser at 40% of maximum nutrient ratio

N	P_2O_5	K_2O	MgO	Total nutrient (%)
9.49	3.25	23.25	4.01	40

Appendix 11

PINIANAKAN FAMILY (Ferralsols)

Soil Classification
FAO/UNESCO LEGEND : Rhodic Ferralsols
USDA Taxonomy : Rhodic Acrudox

Parents Material : Sepertinite

Distribution *(Soil Association key legend in parenthesis)*
Dominant in Bidu-Bidu (41) Soil Association.

Soil Fertility Characteristics

Major nutrient parameters	Nutrients concentration (average of A and B horizons)	Nutrients classification in relation to oil palm requirements	Soil fertility score in relation to nutrients classification
Nitrogen (%)	0.17	moderate	1.00
Available phosphorous (mg kg^{-1})	1.70	very low	1.50
Exchangeable K (cmol kg^{-1})	0.05	very low	1.50
Exchangeable Mg (cmol kg^{-1})	3.08	very high	0.50

Fertiliser Ratio

i. Compound fertiliser ratio (%) for the average FFB yield between 28 to 30 t ha^{-1} yr^{-1}

N	P_2O_5	K_2O	MgO	Total nutrient (%)
0.95	0.33	2.80	0.13	4.21

ii. Compound fertiliser at 40% of maximum nutrient ratio

N	P_2O_5	K_2O	MgO	Total nutrient (%)
9.04	3.10	26.59	1.27	40

Appendix 12

TABLE FAMILY (Ferralsol)

Soil Classification
FAO/UNESCO LEGEND: Orthic Ferralsol
USDA Taxonomy: Typic Hapludox (clayey, oxidic, isohyperthermic)

Parents Material: Basic Igneous Rocks (Basalt)

Distribution *(Soil Association key legend in parenthesis)*
Table (23) Soil Association.

Soil Fertility Characteristics

Major nutrient parameters	Nutrients concentration (average of A and B horizons)	Nutrients classification in relation to oil palm requirements	Soil fertility score in relation to nutrients classification
Nitrogen (%)	0.24	High	0.75
Available phosphorous (mg kg^{-1})	22.33	High	0.75
Exchangeable K (cmol kg^{-1})	0.19	Low	1.25
Exchangeable Mg (cmol kg^{-1})	0.93	Very high	0.50

Fertiliser Ratio

i. Compound fertiliser ratio (%) for the average FFB yield between 28 to 30 t ha^{-1} yr^{-1}

N	P_2O_5	K_2O	MgO	Total nutrient (%)
0.71	0.16	2.33	0.13	3.34

ii. Compound fertiliser at 40% of maximum nutrient ratio

N	P_2O_5	K_2O	MgO	Total nutrient (%)
8.54	1.95	27.90	1.61	40

Appendix 13

TANJUNG LIPAT FAMILY (Acrisols)

Soil Classification
FAO/UNESCO LEGEND: Haplic Acrisols
USDA Taxonomy: Typic Paleudults

Parents Material: Sandstone/mudstone

Distribution *(Soil Association key legend in parenthesis)*
Dominant in Dalit (31), Kretam (33), Lokan (39), and Croker (47) Soil Associations;
Common in Kalabakan (29), Bang (40), Maliu (48), Trusmadi (50), Mawing (30), Rumidi (26) and Gumpal (46) Soil Associations.

Soil Fertility Characteristics

Major nutrient parameters	Nutrients concentration (average of A and B horizons)	Nutrients classification in relation to oil palm requirements	Soil fertility score in relation to nutrients classification
Nitrogen (%)	0.07	very low	1.50
Available phosphorous (mg kg^{-1})	8.63	very low	1.50
Exchangeable K (cmol kg^{-1})	0.07	very low	1.50
Exchangeable Mg (cmol kg^{-1})	0.04	Very low	1.50

Fertiliser Ratio

i. Compound fertiliser ratio (%) for the average FFB yield between 28 to 30 t ha^{-1} yr^{-1}

N	P_2O_5	K_2O	MgO	Total nutrient (%)
1.43	0.33	2.80	0.40	4.95

ii. Compound fertiliser at 40% of maximum nutrient ratio

N	P_2O_5	K_2O	MgO	Total nutrient (%)
11.53	2.63	22.59	3.25	40