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REVIEW PAPER

Oil Palm Mineral Nutrition Management

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ABSTRACT

Irrespective of soil and climate, fertilisation is essential in oil palm cultivation if growth and production potential is to be achieved. It is also necessary for maintaining and improving soil fertility, which is very often a limiting factor on tropical soils.

Oil palm is usually very responsive to fertiliser application. However, significant differences in yield responses between distinct pedo-climatic areas, as well as differential nutrient requirements between mature and immature stages are observed. Manuring generally represents the largest, single component of production cost, accounting today frequently for around 65% of expenditure for maintenance cost in South East Asia, while in the sixties accounted for 54% according to Piggott (1968) in Malaysia. Compared to total production and management cost, fertiliser remains at the first rank (Baskett *et al.*, 2002). Actually scientific methods for management of mineral nutrition that give highly satisfactory results if correctly applied are available. Such management approaches are generally based on the response of the palms, aiming at determining the rate of fertiliser and the nutrient level in the leaf to achieve the best performance. The most performing plantation companies are also looking for a best balance between production level and economic factors. This can be achieved by taking into consideration economical parameters (like the price of palm products and the cost of applied fertilisers) and scenario about their trends, as the time lag between fertiliser applications and the oil palm response can be up to 3 years. Beside these two main factors for fertiliser management, environmental impact of agricultural practices are becoming a major concern for environmentalists and consumers, and it is assumed that this aspect will have to be taken into account in oil palm manuring. Relatively few studies have been carried out on the relation between mineral nutrition of the palms and water management, especially for irrigated palms. Some past results will be presented.

METHODOLOGY FOR MINERAL NUTRITION MANAGEMENT : AN EMPIRICAL METHOD

Talking about fertiliser management for crop cultivation, Gros (1979) emphasize the fact that there is no "master key" acceptable for all types of ecological and economical circumstances, but each situation has to be considered as a specific case. In other words a set of results obtained in one site may not be appropriate in an other site. On the other hand, a general comprehensive methodology can be defined to cover most situations.

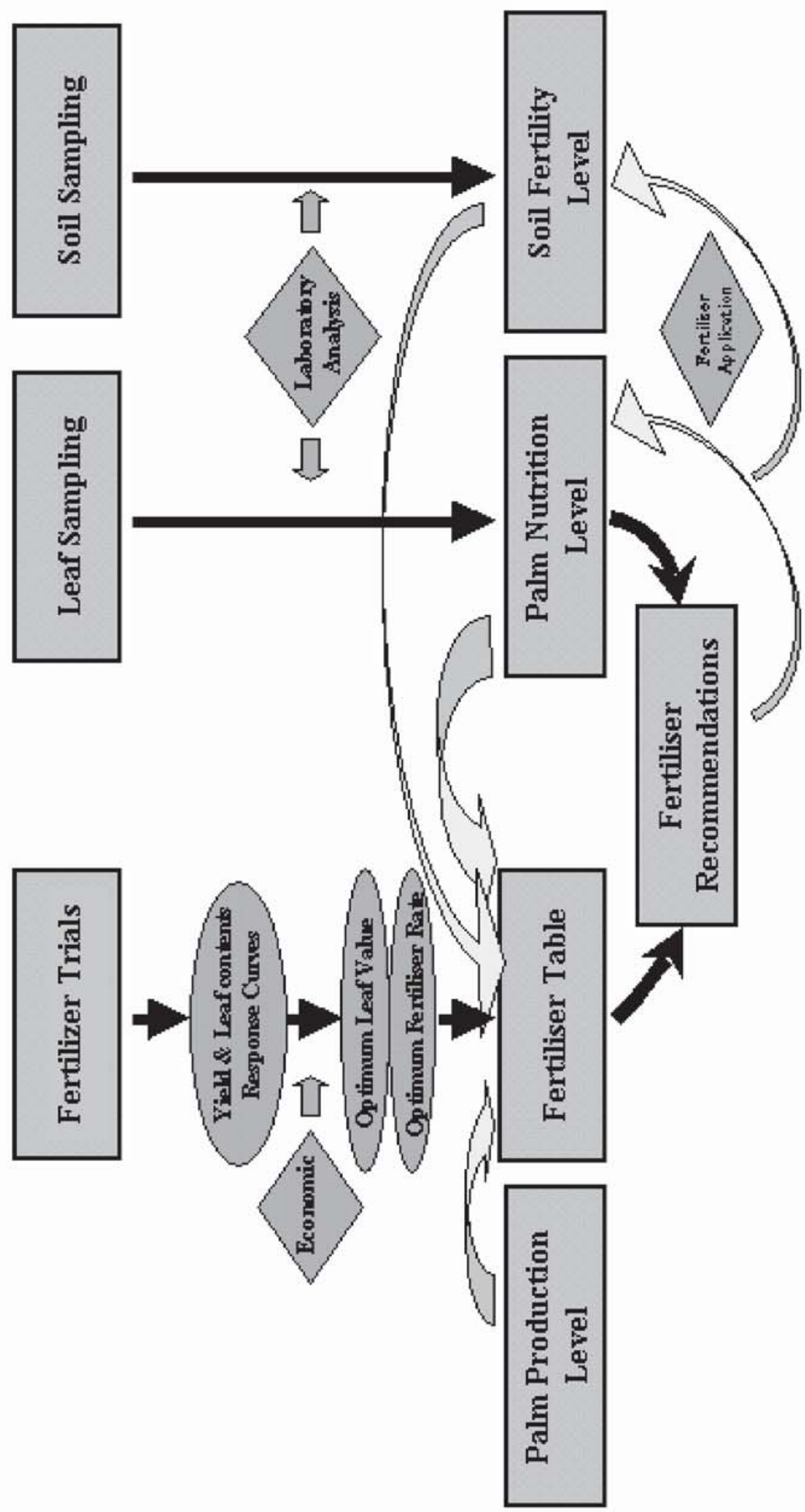
For oil palm mineral nutrition management, the methodology has been described by Ochs (1985). It is an empirical method based on a combination of field experimentation and monitoring of the palms mineral nutrition status through leaf diagnosis.

The first step is to define a land unit area defined as an homogeneous agro-ecological zone, i.e. with similar climatic, soil and planting material characteristics. The size of such a unit may cover from a few hundred up to a few thousand hectares. On each unit area, the decision support system described in Fig. 1 must be run:

- Yield (for mature area), vegetative growth and nutrient leaf contents response curves to the rate of fertilisers can be obtained based on the results of field fertiliser trials. Maximum economical yield and optimum leaf nutrient content can then be calculated, taking into account several economical parameters.
- For each homogeneous block of the estate, the fertiliser rates are recommended depending on the result of plant analysis (leaf sampling).

Fig. 1 - Mineral Nutrition Management: Methodology

- Climate
- Soil Type (characteristics and fertility monitoring)
- Planting material



- Based on plantation performance objectives, agronomists can then establish the fertiliser recommendation programme adapted to each single block.
- Soil fertility monitoring (soil analysis) is necessary to ensure the sustainability of the cropping system.

An extensive fertiliser trials network covering the various ecological situations is required to feed up decision support systems to determine the best strategy to be adopted.

In a major number of situations, yield response curves obtained in fertiliser trials follow the Mitscherlich model:

Y=a–bEXP(-cX) (1)

Where : **Y** = yield or growth
X = rate of fertiliser X
a, b, c constants with following meaning :
a : maximum potential of the palms, defined by all limiting factors except fertiliser X.
b: maximum impact of fertiliser X.
c: relative to the curvature of the response curve.
b * c : slope at the origin = initial efficiency of fertiliser X.

MINERAL NUTRITION MANAGEMENT DURING THE IMMATURE PERIOD

Although the immature period, starting from planting time until the first harvesting round, is a key phase for the future performance of the palms, little appears in the literature about the importance of optimum young palm development during the immature period. The few publications highlight the impact of fertilisation on the performance of palms in terms of production (Ng, 1970; Ng, 1972; Hartley (1988) acknowledged that inadequate fertilisation during the immature period might irrevocably affects the potential of the palms.

The lack of economic returns in the very short term during this period of immaturity may tempt some companies to reduce upkeep costs in young plantings. Yet the considerable susceptibility of young palms to any shortfalls in upkeep is an acknowledged fact. For example, if a fertilisation round is cancelled, rapid yellowing occurs and growth is retarded. Such susceptibility is counterbalanced by the robustness of the palm, which will survive even in highly unfavorable conditions and will end up ensuring a certain degree of production in many cases.

Recently, the importance of an optimum fertiliser management during the immature stage has been stressed by Caliman *et al*. (2002). Based on several trials in South East Asia and in Africa, as well as observations at commercial plantation scale, these authors have established very close relationships between the precocity of young palms or the yield levels recorded during the first 2 to 3 years of harvesting, and their vegetative development during immaturity. In most ecological situations only adequate fertiliser management can ensure the optimum vegetative development of young palms.

In South East Asia, nitrogen is the most common fertiliser application required during the young age together with phosphate, and to a less extend potassium and magnesium. However, a high site specificity is observed based on the characteristics of each soil, and the need for an optimum nutrient balance.

In one experiment in Sumatra (Indonesia), the time to maturity as well as the yield performance during the first year of harvesting are linearly related to the palm vegetative growth during the immature period (Fig. 2, 3). The nitrogen nutrition of the palms appears to be the main factor controlling their vegetative growth (Fig. 4).

In a second experiment, a positive vegetative growth response is observed to phosphorus, nitrogen and to a less extent potassium fertilisation, while magnesium applications did not present any impact (Fig. 5 a, b, c, d). This vegetative growth improvement with N, P and K fertilisers is a consequence of a significant increases of N, P and K nutrition of the palms (Fig. 6 a, b, c). These results confirm the optimum nutrient leaf contents for this type of planting material at that age (Table 1). The yield levels recorded during the first two years of harvesting are closely related to the vegetative development of these palms at the end of the immature period (Fig. 7 a and b). The yield levels observed during the third harvesting year (from month 49 to month 60 after planting) are less-dependant to the vegetative development of the palms during immature stage, although the relation is still highly significant (Fig. 7c).

Table 1 : Optimum nutrient leaf level at 24 months old (Frond 9)

Nitrogen	2.85-2.90 %
Phosphorus	0.175-0.180 %
Potassium	1.35-1.40 %
Magnesium	< 0.28 %

Fig. 2 - Precocity of the palms
Impact of the growth during immature stage

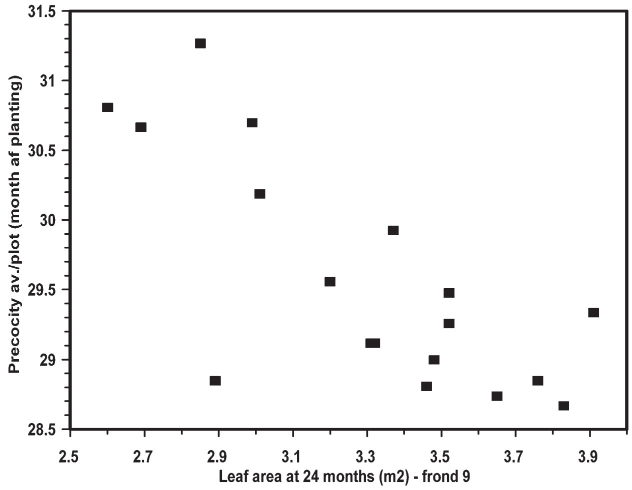


Fig. 3 - Yield of the palms
Impact of the growth

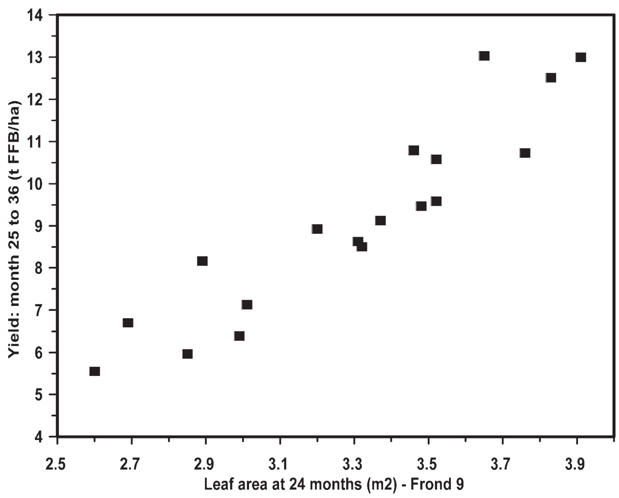
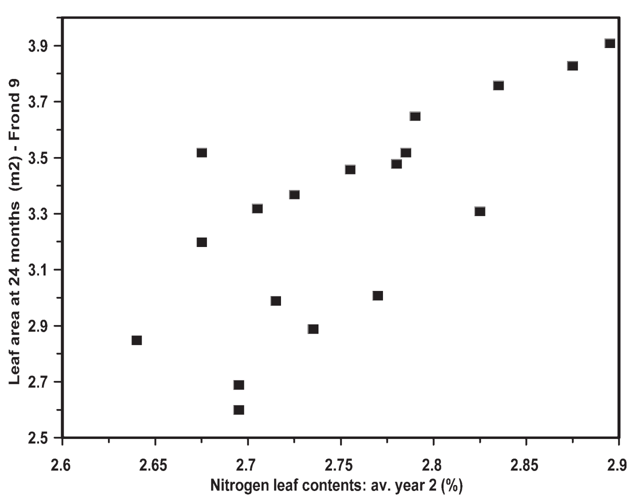
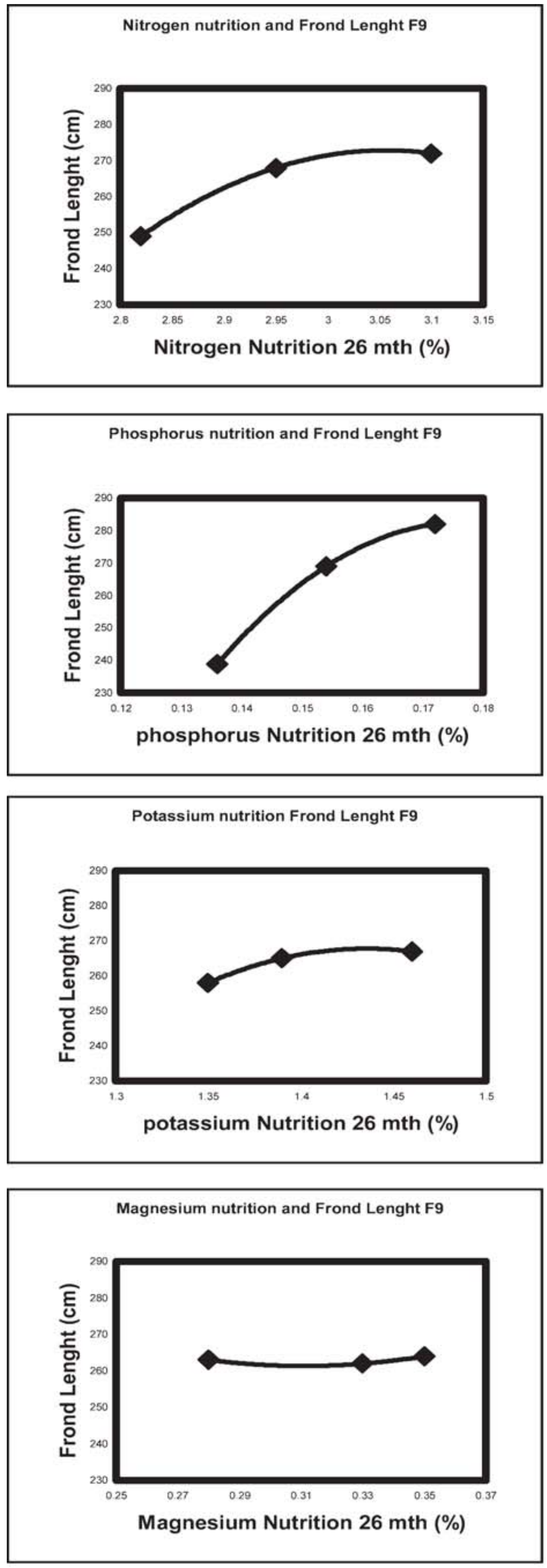
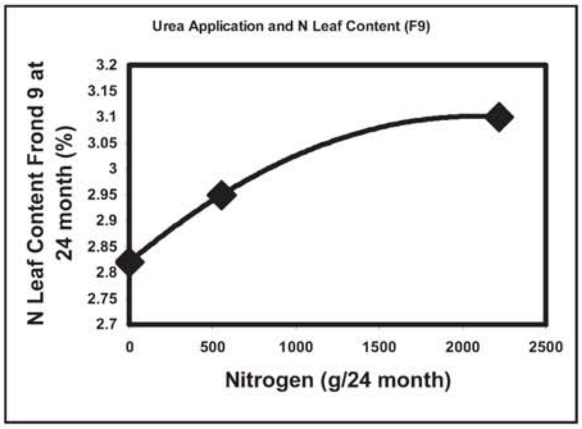


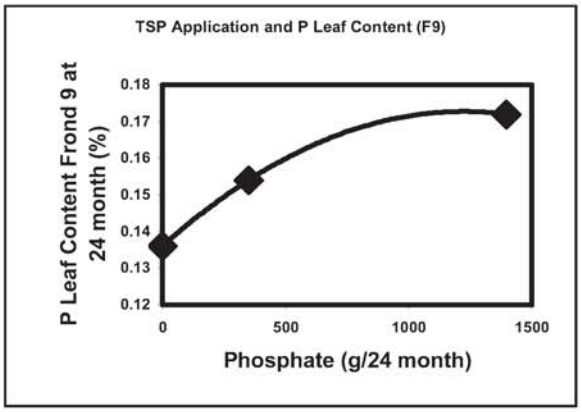
Fig. 4 - Growth of the palms
Impact nitrogen nutrition

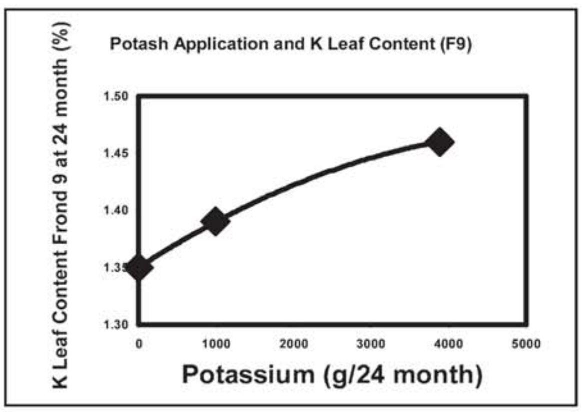


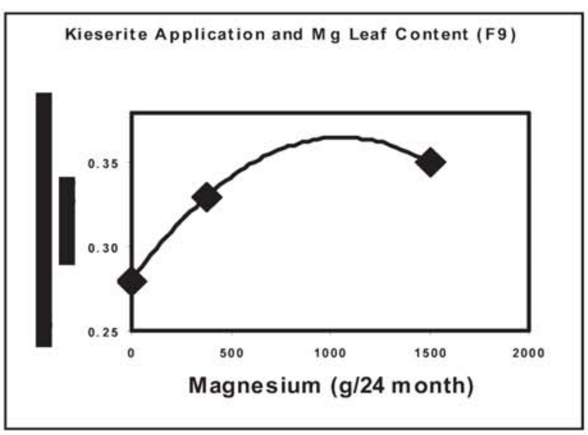


Figures 5 a, b, c, d (from top to bottom)

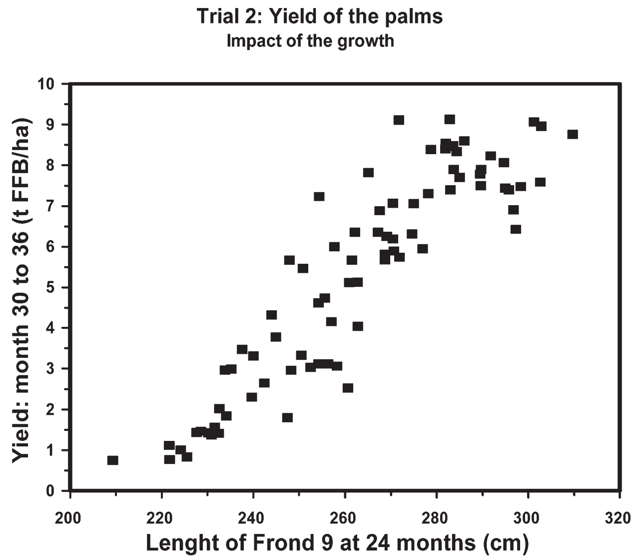


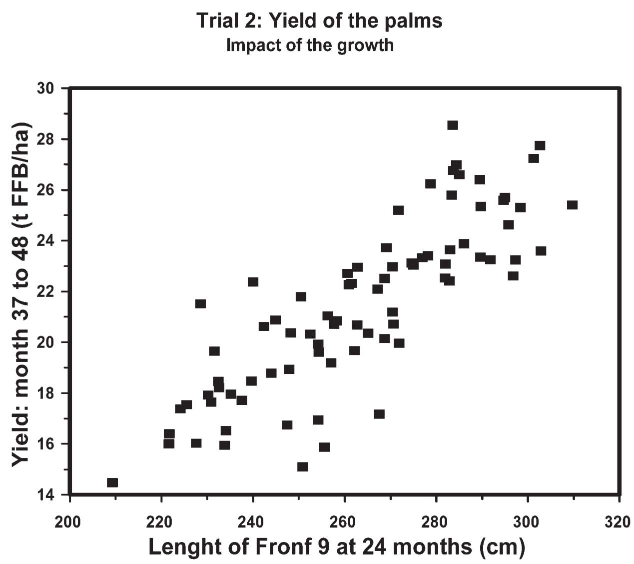


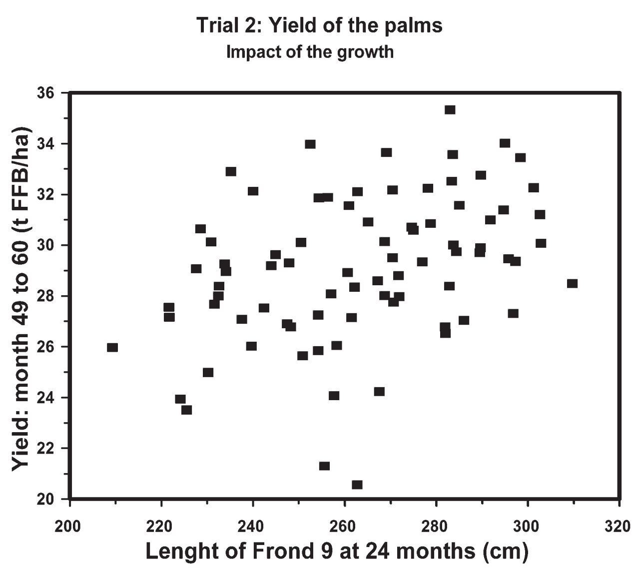




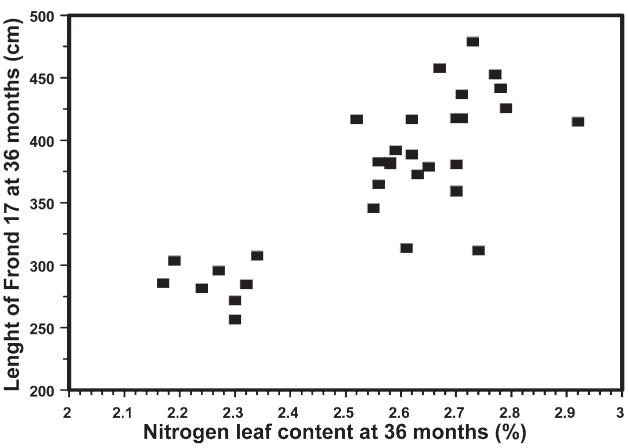
Figures 6 a, b, c, d (from top to bottom)







Similar results can be obtained at commercial scale. Fig. 8a shows the strong impact of the nitrogen nutrition on the vegetative growth (Length of frond 17) of young palms. Subsequently, the yields recorded are very closely related to the vegetative development achieved at the end of the immature period (Fig. 8b).



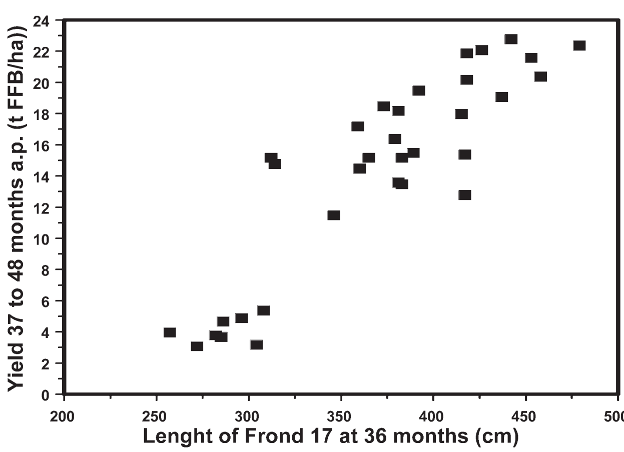


Fig. 8 a and b (from top to bottom)
Observation at an Estate level

One important point to notice is that in these two charts, each dot represents an average value for a thirty hectares block. In addition every block has received the same amount of fertiliser since planting time. Therefore the scattering of the dots indicates the necessity of site specificity management of fertiliser recommendations. There is therefore a need for an appropriate method of monitoring the mineral status of the palms. Leaf sampling is usually implemented yearly, starting at the mature period or just before it, i.e. at 24 months old. An earlier leaf sampling, at 12 months old, would certainly help to optimize the mineral nutrition management in the latest stages of the immature period, but will not ensure a full satisfactory results during the first 12-14 months, where any nutrient deficiency would have significant impact on the growth of the palms.

Therefore, although vegetative growth is the result of all agricultural practices including manuring but also upkeep and land management (drainage, …), it seems that an indicator based on the measurement of one of the growth parameters could be of first help for an early detection of under-performing areas and then-after possible local adjustments of the fertiliser regime of the palms, if nutrient deficiency is confirmed. The advantage of such an indicator is that it is straight forward as the results are readily available, relatively cheap and easy to implement at high frequency (every 6 months) and therefore makes possible early corrective actions.

As most of vegetative parameters like frond length, girth circumference, petiole cross-section, frond area or relative frond area, are closely correlated each other, any of them could be chosen as an appropriate indicator, the easiest to implement being probably the length of the frond, measured from the top extremity to the limit of leaflet.

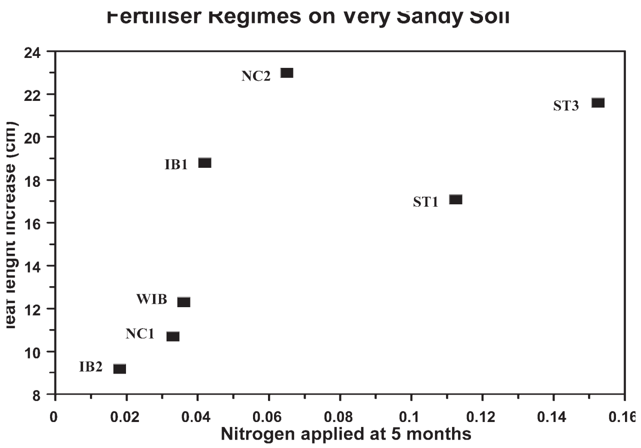
Scoring of the indicator could be done by comparison to an optimal growth curve, established before hand for each ecological situation and each planting material based on trials results, or by comparison between areas within the same estate. Subsequently, general investigation about under-performing areas, including specific leaf sampling will allow to take rapidly any necessary corrective action.

CHOICE OF FERTILISER TYPE FOR IMMATURE PALMS

Generally speaking straight fertilisers give very good results as far as they are used with appropriate care. For example nitrogen volatilization from urea can be reasonably limited when the fertiliser is applied during the wet season, and slightly mixed with the topsoil in the circle. Ammonium sulfate is recommended in location where sulfur is a limiting factor and if no other form of fertiliser containing sulfur is applied to the palms in enough amounts.

Limited access to manpower is usually the reason why many companies prefer applying compound fertilisers rather than straights despite the higher cost of the previous one. This results in a reduction of the number of application rounds, so that scarce manpower can focus on other tasks like harvesting of mature areas. Finally the total cost of compound applications (cost of fertiliser + cost of application) is often higher compared to straight fertilisers, even through a slight reduction of the rate of compound is sometime suggested.

On specific situation like very sandy soils (texture with 90% of sand), high quality coated fertilisers give very good results in terms of efficiency per unit of nutrient applied, especially in the very short term (Fig. 9a, b). However, an appropriate fertiliser regime using straight fertilisers can also give as good results on the development of the palms. It remains to compare the "energy" required for both type of fertilisers, but for the time being, these quality-coated fertilisers present such a high price that they are very scarcely used in oil palm plantation.



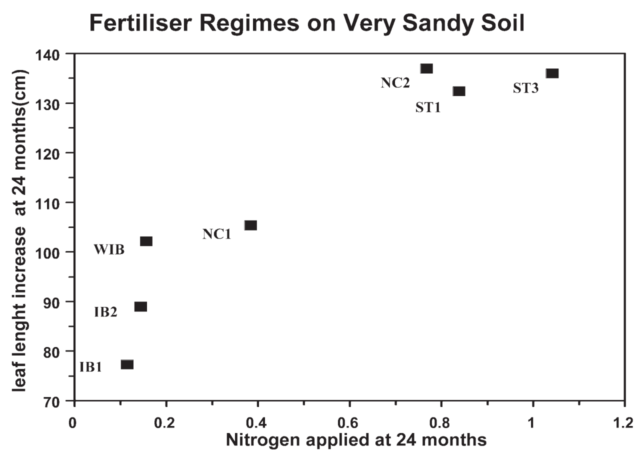


Fig. 9 a and b

ST1 = standard fertiliser regime for immature palms on mineral soil.
ST3 = fertiliser regime for immature palms adapted for very sandy soil (higher frequency and rates.
NC1 = coated slow release fertiliser at rate 1
NC2 = coated slow release fertiliser at rate 2
IB1 = compound fertiliser at rate 1
IB2 = compound fertiliser at rate 2
WIB = tablet fertiliser during year 1, and compound fertiliser during year 2

MICRO-NUTRIENT REQUIREMENT: SPECIFIC SITUATION

There are a number of situations where micronutrient fertilisers have to be applied to the palms. The most frequent is on peat soils where copper, zinc, boron and sometimes iron must be supplied. It is not the objective of this paper to review all these situations. Nevertheless, as an example, it is interesting to present some results obtained on very sandy soils, where a copper deficiency can often be observed.

Copper deficiency is not very often mentioned in the literature unless on peat soil (Ng and Tan, 1974; Gurmit, 1982). One case has been observed in Brazil on tertiary sedimentary soil (Pacheco *et al.*, 1986). In Sumatra, on very sandy soils (80 to 95% of sands), copper deficiency symptoms appear on young palms shortly after field planting. Beside the typical yellowing foliar symptoms, the growth of the palms is highly affected. Field fertiliser trials show that regular copper sulphate applications since planting time can prevent the occurrence of this deficiency. An application of 10g of $CuSO_4$ in the planting hole, followed by application of 12.5g every 3 months, give very good results in terms of palms growth (Table 2).

Leaf analysis results show that the optimum Cu content for fronds 3 and 9 is around 5ppm.

MINERAL NUTRITION MANAGEMENT DURING THE MATURE PERIOD

During the mature period, the key final indicator for the planter is the yield of the palms. Indeed, although yield is not an optimum scientific indicator as it is the result of the whole set of agricultural practices, it represents the income that planter will put in his budget.

As mentioned before, one of the pillars of the methodology consist in establishing yield and leaf nutrient content response curves to the rate of fertiliser

Table 2 : Copper application, leaf analysis and growth

	Planting Hole (g/palm)	Surface application (g/palm/year)	Frond 9 length (cm)	Cu leaf content	
				Frond 3 (ppm)	Frond 9 (ppm)
Cu0	0	0	182	2.3	2.3
Cu1	10	30	208	4.5	4.2
Cu2	10	60	232	5.0	4.8
Cu3	10	90	233	5.7	5.0

applied in field trials. Economical parameters, targeted yield level, and soil fertility trends are also taken into consideration.

As an example, in North Sumatra (Indonesia) on sedimentary soils, two fertiliser trials have been set up to study the mineral nutrition of mature palms (7 years old at the beginning of the trial) relative to four major nutrients N, P, K and Mg. Positive responses of the yield have been observed for urea, MOP and kieserite applications, with an antagonism between K and Mg (Caliman *et al*., 2001).

Fig. 10 presents the yield response curves (based on the Mitscherlich model (2)) fitted to the average results recorded during the 10 to 12 years old period, for each fertiliser (Urea, MOP and Kieserite). In order to "reduce" the impact of the antagonism between K and Mg nutrition in this specific study, low rates of kieserite have not been part of the analysis for the response curve to MOP application. Likewise, low rates of MOP have not been part of the analysis for the response curve to kieserite application.

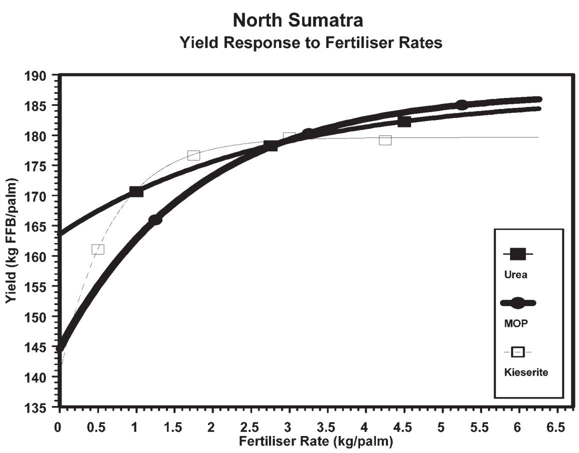


Figure 10 (From Caliman et al. (2001))

Table 3 : Parameters of Mitscherlich yield response curves to fertiliser

Fertiliser	a_m	b_m	c_m	b_m * c_m
Urea	186.7	23.2	0.37	8.5
MOP	187.3	42.7	0.56	23.8
Kieserite	179.6	39.4	1.51	59.4

(Caliman *et al.* (2001a)

$YIELD_m = a_m - b_m$ EXP(-cm FER_m) (2)

with : **$YIELD_m$** = yield response to fertiliser **m**

FER_m = rate of fertiliser **m**.

a_m, b_m, c_m = constants described earlier, respective to fertiliser **m**.

- The **a** values show that N and K are limiting factors for the yield of the palms when kieserite is no more limiting.
- The **b** values shows that MOP applications have the strongest impact in terms of yield improvement (42.7 kg Fresh Fruit Bunches/palm/year). The lowest one is obtained with urea application (23.2 kg FFB/palm/year).
- The **a** and **b*c** values show the very high efficiency of small rates of kieserite applications (at low fertiliser regime, an additional unit of kieserite applied results in an increase of 59.4 units of FFB/palm/year).

This Mitscherlich model reflects the point that the level of yield increase declines when the fertiliser rate increases. It is clear that beyond a certain dosage, any additional fertiliser application cannot be paid back by the small corresponding increase of yield.

This point is called the optimum fertiliser rate (**OFR**), which gives the maximum economical yield. This optimum fertiliser rate depends on the generated income (related to CPO price **Pyield**), and on the cost of fertilisers **Pfer**. These two parameters can be presented through a financial ratio **R = Pfer / Pyield** giving the number of units of FFB required to pay back a unit of fertiliser applied.

The **OFR** can be calculated from the economical efficiency curve specific to the fertiliser

m : **dYIELDm/dFERm = bm*cm EXP(-cm FERm) (3)**

This curve shows the economical efficiency of the fertiliser applied, in other words the expected increase of yield subsequent to an addition of one unit of fertiliser. The maximum profit is obtained for an efficiency equal to **R**:

dYIELDm/dFERm = bm*cm EXP(-cm OFR) = Rm (4)

then : **OFRm = -1/cm LN(Rm/ bm*cm)** (5)

Subsequently the nutrient leaf content response curve gives the corresponding value of the optimum potassium leaf content **Kopt**. **FOLm = aFm – bFm EXP(-cFm FERm)** (6) with : **FOLm** foliar content with application of fertiliser rate **FERm**. **Mopt = aFm – bFm EXP(-cFm OFRm)** (7) with : **Mopt** optimum leaf content of nutrient **m**, relative to optimum fertiliser rate **OFRm**.

Fig. 11 and 12 show the economical efficiency curve, and the determination of **OFR** and **Kopt** relative to the potassium fertiliser in the previous example in

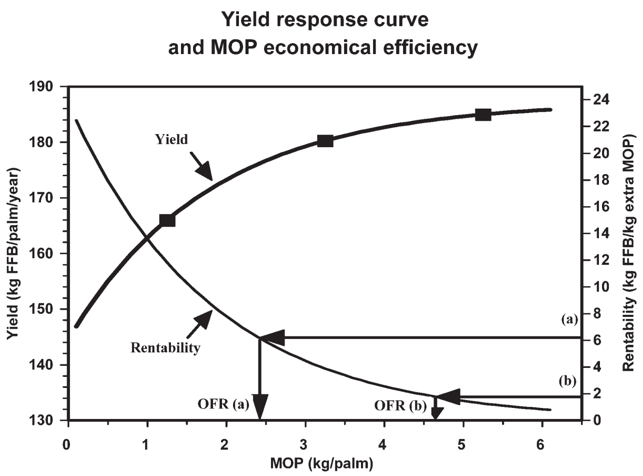


Figure 11 (From Caliman et al. (2001))

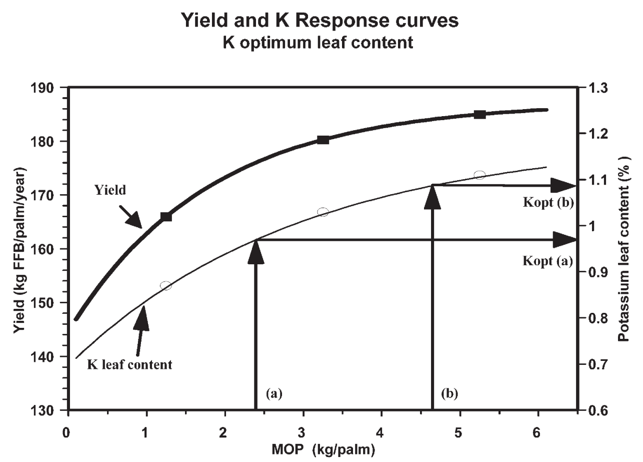


Figure 12 (From Caliman et al. (2001))

Table 4 : optimum economical fertiliser rate (OFR) and nutrient leaf content Mopt

		Urea	Potash (KCl)	Kieserite
P_{fer}	(US$/t)	122.3	143.8	91.2
$R= P_{fer}/P_{pro}$		5.3	6.3	4.0
OFR	(kg/palm)	1.3	2.4	1.8
M_{opt}	(%)	2.50	0.97	0.19

- Cost of production= 150 USD/tonne CPO
- Oil Extraction Rate: OER = 23%
- Income= 250 USD/tonne CPO (± 300 USD/tonne CPO CIF Rotterdam)

(Caliman *et al.* (2001a)

North Sumatra. Table 4 presents **OFR** and **Mopt** related to the three fertilisers from the North Sumatra example.

It has to be emphasized that the value of **OFR** is specific to the trial conditions, where the same rate of fertiliser has been applied every consecutive year. In commercial field situation, the optimum rate may differ depending on the historical fertiliser regime of the palms. On the other hand, the optimum nutrient leaf content values have been shown more independent of the history of the palms.

These two parameters (**OFR** and **Mopt**) as defined previously are the basis keys to build up a fertiliser recommendation programme. Indeed it is therefore possible to determine the rate of fertiliser to be applied in each estate block based on the palm nutrition level (8a) (8b):

FERmi = OFRm – COR mi (8a)

with : **FERmi** is the rate of fertiliser **m** to be applied on commercial block **i.**

CORmi is the corrective rate of fertiliser **m** relative to commercial block **i**.

then : **CORmi = OFRm – FERmi** (8b)

and : **CORmi = -[1/cTFm LN((aTFm -FOL mi)/ bTFm)] -[1/cm LN(Rm/ bm*cm)]** (9)

with : **FOL mi** is the nutrient **m** foliar content observed on commercial block **i**.

Fig. 13 shows the variations of the potash corrective rate for a wide range of potassium nutrition levels. Expected yield increase can be forecasted from these curves. It is also possible to quantify the impact on yield and the cost of any over-fertilisation.

As a conclusion, the standard fertiliser recommendations for the palm can then be based on the following four components:

- the current nutrition palm status revealed through the leaf content value **FOLm**,

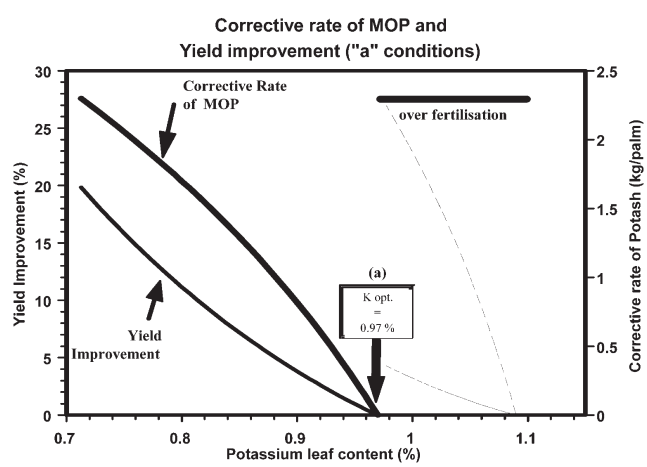


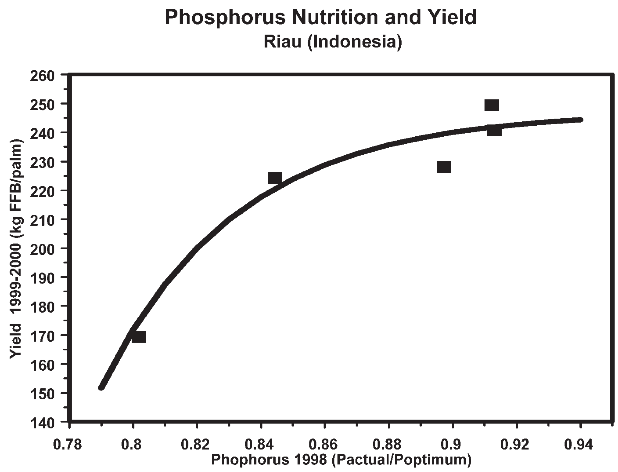
Figure 13 (From Caliman et al. (2001))

- the optimum nutrient level **Mopt** targeted,
- the optimum fertiliser rate **OFR**,
- the corrective fertiliser rate **COR** which is related to the intensity of the response curve observed in the fertiliser trial,

BASIC BIOLOGICAL BALANCE BETWEEN NUTRIENTS

Mineral nutrition studies and management have to take into consideration basic biological balances between nutrients. Most of them are well known by oil palm agronomists as the consequence is often visible through antagonisms or synergies in nutrients absorption. For example the trend for a decrease of the nitrogen optimum leaf level with the age of the palm, the frequent antagonism between potassium and magnesium absorption, the synergy between potassium and copper, calcium and chlorine, etc…

One interesting case is the synergy between the nitrogen and phosphorus nutrition observed in Sumatra



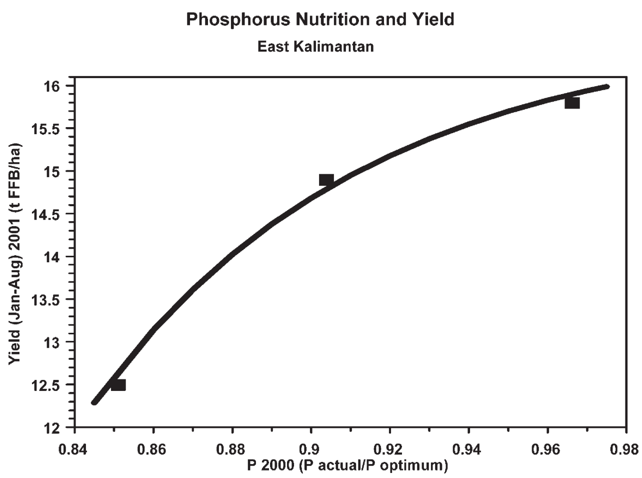


Fig. 14 a, b (from top to bottom)

(Tampubolon *et al.*, 1990) and other situations (Foster, 1993). The consequence is that phosphorus impact should be analyzed considering the relative value to an optimum determined based on the level of nitrogen. In a trial about phosphate fertilisers in Sumatra, a close relationship is observed between the yield level and this relative P value (Fig. 14a). Similar result is obtained on young palms in commercial blocks in Kalimantan (Fig. 14b).

IMPORTANCE OF ECONOMICAL PARAMETERS

During the last decade, CPO price has fluctuated between US$ 255 and 700/tonne. These variations are part of cycles with frequency and amplitude related to changes in the production and consumption levels, and stock balance (Oil World, 1999). These parameters depend on natural events (climate variations), but also on changes in agricultural policies in major importer countries.

To some extent such kind of variations may have to be considered by plantation companies, in order to adjust their production cost to the commodity price and possible scenario about their short and mid-term evolution. Several authors have shown that the optimum fertiliser rate largely depends on CPO (Gunn, 1962; Piggott, 1968; Ng, 1972, Lo and Goh, 1973; Ochs and Ollagnier, 1977; Ochs, 1985; IRHO-CIRAD, 1992; Caliman *et al.*, 2001). It is therefore understandable that oil palm fertiliser regime has to be adapted not only to ecological situations as it is usually accepted and implemented, but also to economical parameters in order to maximize profit.

Equation (5) previously defined shows that the **OFR** (Optimum Fertiliser Rate) is directly depending on the ratio **R** between the cost of fertiliser and the price of CPO. Consequently the optimum nutrient leaf content **Mopt** also vary with **R**, as it depends directly on the **OFR** value (7). In the example of North Sumatra Fig. 11 and 12 show the level of **OFR** and **Kopt** when the CPO price changes from US$ 300 /tonne (situation a) to US$ 550 /tonne (situation b), the cost of MOP remaining unchanged. Table 5 summarizes these situations and parameters.

Significant differences are observed between the two values of OFR relative to MOP, with 2.4 kg/palm and 4.65 kg/palm for situation a and b respectively. Fig. 15a and 15b show the variations of **OFR** and **Kopt** with both CPO and MOP prices, while Fig. 16 shows **OFR** and **Kopt** variations with CPO price only, MOP price remaining unchanged . Similar analysis could be done about the other fertilisers being part of the standard fertilisation regime.

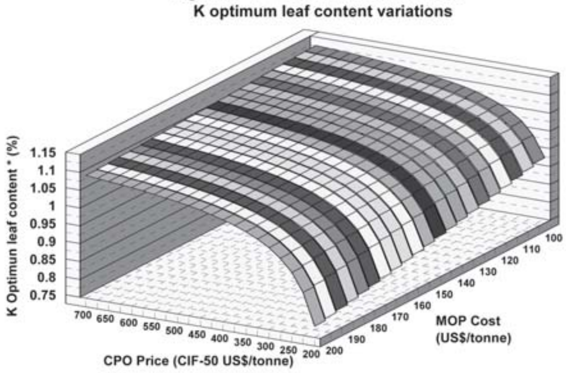
Table 5 : Optimum Economical fertiliser rate (OFR) of MOP, and optimum K leaf content (Kopt) based on two economical situations

	Situation a	Situation b
CPO (US$/t)	300	550
R= Pfer/Ppro	6.3	1.8
OFR (kg/palm)	2.4	4.65
Mopt (%)	0.97	1.09

- Cost of KCl: **Pfer = 143.8 US$ / tonne**
- Cost of production= 150 USD/tonne CPO
- Oil Extraction Rate: OER = 23%
- Situation a: Income= 250 USD/tonne CPO (± 300 USD/tonne CPO CIF Rotterdam)
- Situation b: Income= 500 USD/tonne CPO (± 550 USD/tonne CPO CIF Rotterdam)

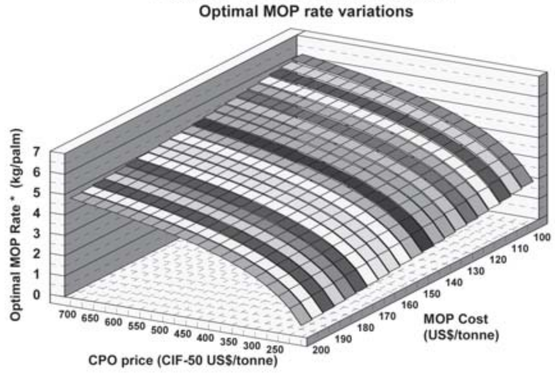
(Caliman *et al.* (2001)

Fig. 15a - Potassium Fertilisation
K optimum leaf content variations



*: in Fertiliser Trial Situation (North Sumatra - Sedimentary Soils)

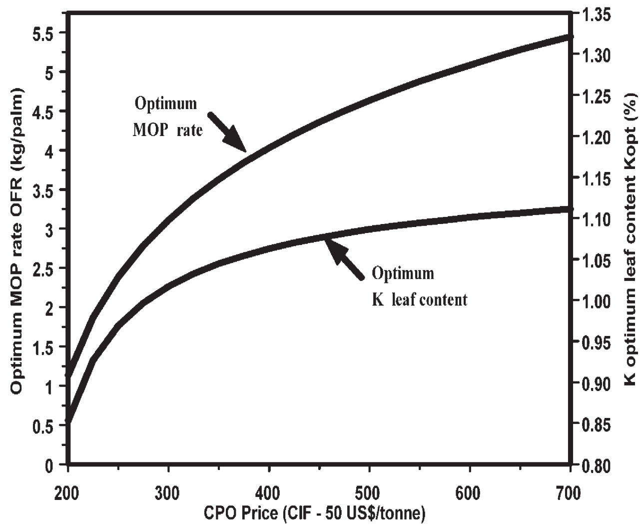
Fig. 15b - Potassium Fertilisation
Optimal MOP rate variations



*: in Fertiliser Trial Situation (North Sumatra - Sedimantary Soil)

These results confirm that the mineral nutrition management of oil palm plantations and the fertiliser recommendations should not follow a static procedure, but should be adapted to the economic environment, as far as possible scenario for commodity prices can be clearly forecast, and keeping in mind the time-lag between any change in the fertiliser regime and the reaction of the palms which can reach up to 3 years.

Fig. 16 - OFR and K opt relative to MOP
North Sumatra - (MOP = 145 US$/tonne)



ADJUSTMENTS OF THE STANDARD FERTILISER RECOMMENDATION RATE

There may be mainly two reasons calling for an adjustment of the calculated fertiliser recommendation rate:

- companies facing a temporary cash-flow problem.
- expected yield significantly higher or lower than usual.

Companies facing a temporary cash flow problem may have no other choice than reducing production cost including fertiliser expenditure. Fertiliser rationing should be the last stage, priority for savings being targeted first:

- in cheaper substitutes for expensive fertilisers, for example through a maximization of the valorization of factory wastes (Empty Fruit Bunches, Effluent, …).
- in a maximization of the efficiency of any amount of fertiliser applied.

Should fertiliser rationing be finally necessary, the implementation of such a policy should be very selective in the type of fertiliser to be reduced, and the palms concerned. The objective is to limit as far as possible negative impact on the future performances of the palms.

In the example from North Sumatra presented before, the yield response curves give an opportunity to assess, to some extent, the impact of rationing (10a). Although rationing policies are not expected to last for a long period, such analysis provides some tool for decision-making.

dPROm = PROm opt -PROm rat (10a)

with : **dPROm** is the yield impact related to the rationing rate **rat** of fertiliser **m**.

PROm opt is the optimum economical yield related to the yield response curve to the fertiliser **m**.

PROm rat is the expected yield related to a permanent rationing of fertiliser **m**.

then : **dPROm = bm [EXP(-cm OFRm (1 – rat)) -EXP(-cm OFRm)]** (10b)

As no effect of phosphate fertiliser applications has been recorded since the beginning of the trials, phosphate must be the prioritized fertiliser in terms of rationing, on commercial blocks where P leaf contents are of the same order or higher than the one observed in the trials. About urea, MOP and kieserite, Fig. 17 show the expected yield decline relative to continuous rationing. When the past fertiliser regime is high (corresponding to high CPO prices = US$ 550 CIF/ tonne), rationing below 60% of initial fertiliser rates should focus on kieserite as the expected yield decline will be more limited than rationing urea or MOP (Fig. 17a). This last one (MOP) will have the highest negative impact. When the past fertiliser regime is moderate (corresponding to low CPO prices = US$ 300 CIF/ tonne), rationing below 80% should follow a different sequence: urea, then kieserite and finally MOP (Fig. 17b).

Fig. 17a - North Sumatra
Fertiliser Rationing and Yield

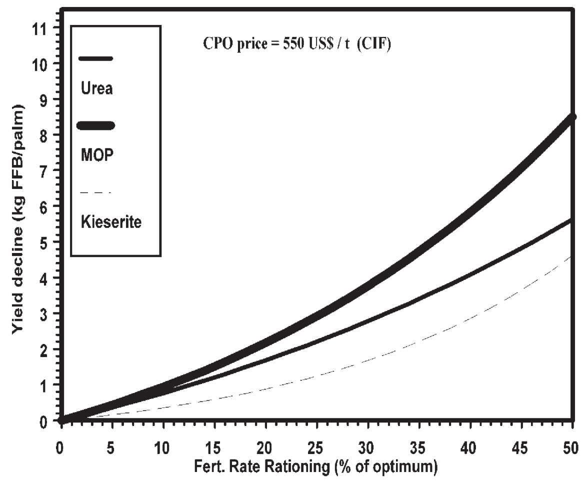
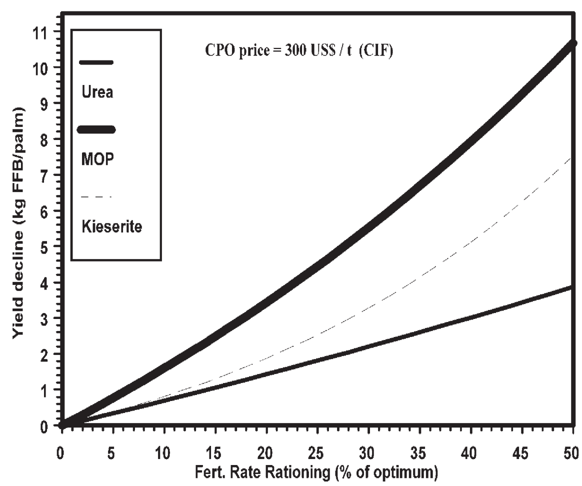


Fig. 17b - North Sumatra
Fertiliser Rationing and Yield



The difference of behavior between urea and kieserite is due to the difference of the shape of the yield response curve of the two fertilisers: as already mentioned earlier in this paper, low fertilisation regime for kieserite have high impact on palm yield. Of course it has to keep in mind that a minimum balance must be kept between nutrients. Therefore "prioritized fertiliser" in terms of rationing does not systematically means than 100% of this fertiliser has to be cut before rationing a second one.

These conclusions do not take into account any possible persistent effect of past fertiliser applications (especially in our example with MOP and Kieserite), nor the fact that such rationing measures will probably be temporary. Nonetheless it gives an idea of the maximum impact that can be expected.

When production forecasts show significantly higher yield (for example following two years of very low production) or lower yield than normal (for example the campaign following a severe drought), it can be advisable to adjust the fertiliser regime in order to take into account variations in nutrients removal by the crop. Based on data presented by Ng L and Thamboo (1967), the impact of a variation of 5 tonnes of fresh fruit bunches is presented table 6.

This table gives an idea of the level of adjustment in fertiliser rates that could be recommended. However, such policy is mainly applied when high yield is expected, but scarcely when low production is forecasted.

Table 6 : Nutrients removal by oil palm crop. (Ng and Thamboo (1967))

	N	**P**	**K**	**Mg**
Nutrient removal by 25 t FFB (kg/ha)	93.5	11.0	92.7	19.3
Fertiliser equivalent for 5 t FFB (kg/palm)	**Urea** 0.280	**TSP** 0.080	**MOP** 0.250	**Kieserite** 0.160

OIL PALM MINERAL NUTRITION AND IRRIGATION

Very little literature can be found about mineral nutrition management on irrigated palms, since irrigation is still not a common practice on oil palm cultivation. The experiment carried on in Ivory Coast by Prioux *et al*. (1992) was focussing on Potassium and Phosphorus nutrition. The K3-P3 trial (3 rates of muriate of potash and 3 rates of single super phosphate) confirmed that the potassium level in the leaf was relatively low in the irrigation trial. The K critical level was estimated at 0.85 % (actually currently close to 0.90% at current palm oil price) compared to a usual level of 0.95 % without irrigation in that relatively dry area (average water deficit = 448 mm/year during the period of the trial). This seems to confirm the finding of Ollagnier *et al*. (1987) showing a link between the critical level for potassium and the water supply to the palms: situations without water deficit showed significantly lower potassium critical level compared to situations with average water deficit. The explanation provided by Ollagnier was based on the dual role of potassium, i.e. nutrient and element favouring drought resistance: without water deficit, potassium was no more required for stomatal opening mechanisms.

Phosphorus optimum level was in accordance with the Nitrogen-Phosphorus balance mentioned just above in this paper.

Consequently, Prioux (1989) was used to apply part of the fertilisers required by the palms through the irrigation water (fertigation), and part during the rainy season without irrigation, in order to have an homogeneous distribution of nutrient supply to the palms throughout the year. One kilogramme of Muriate of postash was applied every year through the irrigation scheme (at a rate of 7g/palm per hour of irrigation, with a concentration of 0.05g/liter), plus an additional 1 to 2 kg per palm per year during the rainy season.

OIL PALM MINERAL NUTRITION MANAGEMENT: PROSPECTS

A tentative evaluation of the requirements in terms of Research for a further improvement of the mineral nutrition management of oil palm would result in a long list of interesting topics.

Obviously, a move toward precision agriculture, based on the development of appropriate GIS system, probably using remote sensing technology will result in an increase of the efficiency of the applied fertiliser, through fine-tuning of applications in both space and time scale (Nguyen *et al*., 1993; Fairhurst *et al.,* 2000; Wanasuria *et al*.,1996).

In this paper we would like to mention three key subjects that we believe should be developed in the future:

- The environmental impact of fertiliser management.
- The bio-disponibility of nutrients in the soil, and the relation with the palms.
- The characterization of the planting material.

THE ENVIRONMENTAL IMPACT OF FERTILISER MANAGEMENT

The impact of agricultural practices on the environment has become a major issue for environmentalist groups (NGO) and consumers. Oil palm cultivation and development is included in activities targeted by NGOs. The challenge for the stakeholders is to develop sustainable production systems in its wide $\mathbf{P}^3$ definition: Planet (environment), People (social), Profit (economical).

For mineral nutrition management, the challenge will consist in providing enough nutrients to the palms in order to achieve its potential, without any risk to the environment (surface and ground water pollution) and maintaining natural resources (no mining of the soil or natural deposit).

The nutrient balance approach should allow agronomists in making short, medium and long-term assessment of the land quality, as well as forecasting undesirable environmental effect such as surface and ground water pollution or soil nutrient mining. Nutrient budget should be systematically established along with fertiliser recommendation program.

In addition, an environmental risk response curve should systematically be built up, along with the yield response curve obtained in the fertiliser trials. For example Fig. 18 a, b, c show a tentative calculation of the environmental risk related to the fertiliser trial in Sumatra mentioned early in this paper. The estimation is based on the nutrient immobilization, removal and recycling proposed by Ng and Thamboo (1967). Here the environmental risk is the difference between the palm requirements and the amount of nutrient applied, and presented in absolute value. The unit is in kilogram of nutrient per hectare. **ZR** represents the rate of fertiliser with a theoretical zero risk onto the environment. A lower fertiliser application regime will lead to a mining of the soil nutrient fertility, while higher fertiliser application rates will result in possible ground water pollution and a mining of natural deposit for potash, phosphate and kieserite for example.

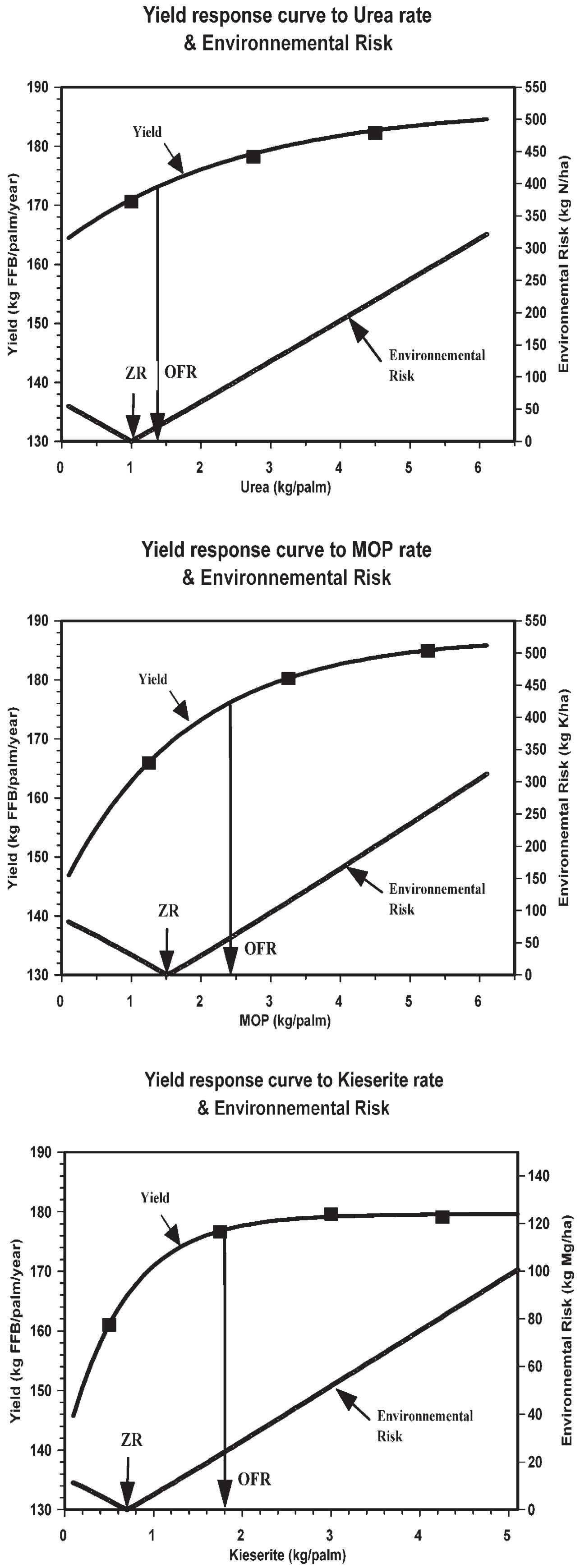


Fig. 18 a,b,c (from top to bottom)

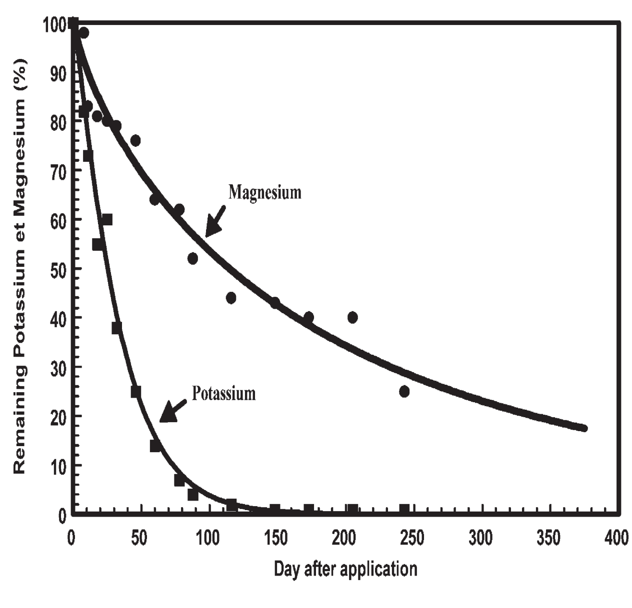
The main challenge for researchers will be to develop agricultural practices where the **OFR** and **ZR** will be confounded, in order to maximize productivity while minimizing the environmental risk.

All these studies should results in the definition of specific indicators and the corresponding scoring system useable by planters and agronomists to evaluate the environmental impact of their practices.

A second source of worries, related to some extent to the mineral nutrition management, is about the valorization of factory wastes in oil palm plantation. For each tonne of CPO produced, the oil palm industry has also to deal with around one tonne of empty fruit bunches (**EFB**) and three tonnes of palm oil mill effluent (**POME**). The high organic nutrient value of these products makes it possible a valorization through a substitution for mineral fertilisers. Several studies have confirmed the positive impact of EFB field application on the palms nutrition. (Loong *et al.*, 1987; Lim and Chen, 1989; Hornus and Nguimjeu, 1992). More recent studies have revealed the kinetics of nutrients release from EFB after field application (Fig. 19a, b), and the positive impact on the soil chemical (Fig. 20) and physical characteristics (Fig. 21) (Caliman and *et al.*, 2001b; Cirad, 2001).

The situation is different for POME. In many cases, the recommended rate for land application, which can be as high as 750 m^3/ha results in a very low nutrient efficiency, down to five or even seven times lower than the use of mineral fertilisers. In addition, where the flatbed application system is used, the

Fig.19 a - Dynamic of K and Mg release from EFB after field application



environmental risk seems not negligible. For example the very high potassium content may represent a risk of ground water pollution, as well as for the soil physical stability. More research should be done in that field.

Fig.19b - Dynamic of N and P release from EFB after field application

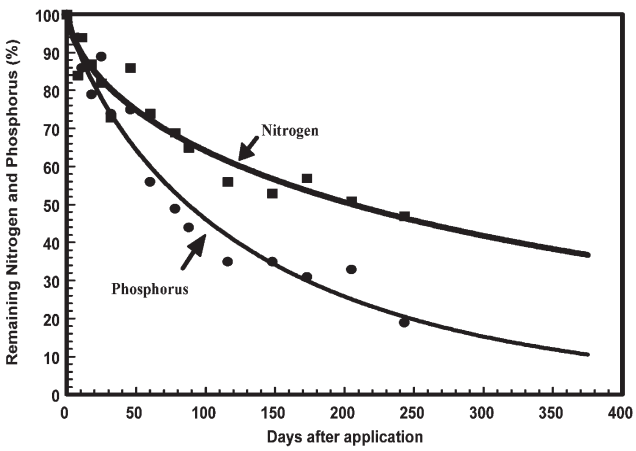


Fig. 20 - Variation in exchangeable K in the soil after EFB application

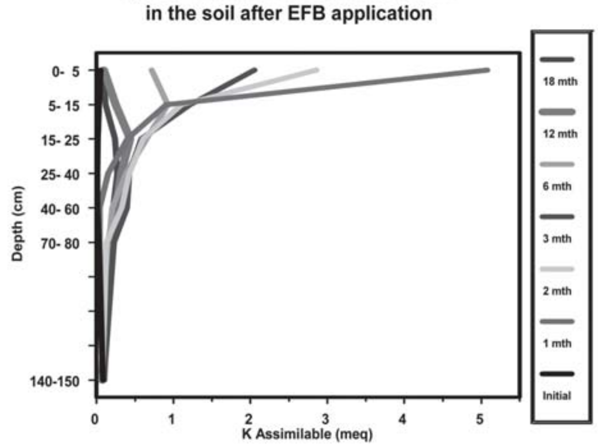
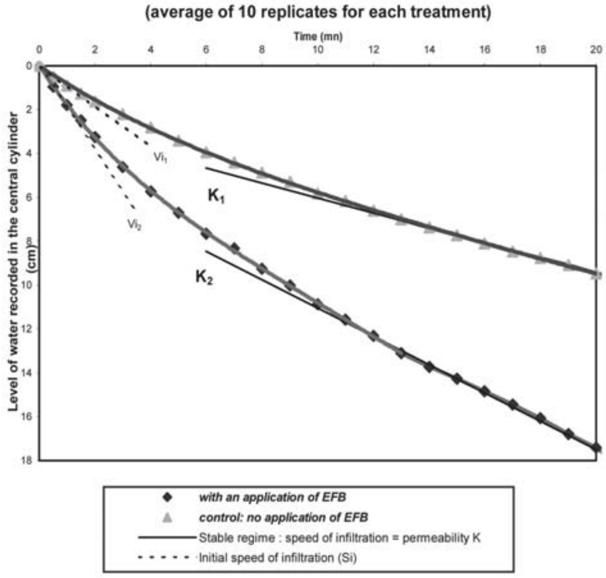


Fig. 21 - Soil permeability (K) (average of 10 replicates for each treatment)



MINERAL NUTRITION MANAGEMENT: TOWARDS A FUNCTIONAL APPROACH

The trend towards sustainability seek for Agronomists to be more explanatory, in order to improve and optimize agricultural practices. About fertiliser management, this could be achieved through a better knowledge of the bioavailability of the nutrients in the soil and the palms. Then functioning models could be developed and integrated in the models currently developed related to carbon assimilation.

These studies should include:

- At the soil level: an evaluation of the balance between nutrients, their availability for the palms.
- At the palm level: an evaluation of the palm requirement for each nutrient at each stage of vegetative and reproductive development.
- An evaluation of the palm reserves and the kinetic of their mobilization.

Finally comprehensive studies about nutrient cycling in the oil palm agro-system as a whole must be launched.

MINERAL NUTRITION MANAGEMENT: TOWARDS A CHARACTERIZATION OF THE PLANTING MATERIAL

There are an increasing number of studies showing significant differences in mineral nutrition status of different planting material (Gnayoro, 1992; Caliman *et al*., 1994; Jacquemard *et al.,* 2002). They do not yet allow specific fertiliser management, as respective optimum leaf content levels and needs for specific fertiliser rates have not been proven yet.

As the planting material proposed by breeders and seed suppliers will most probably be more and more homogeneous within categories, up to a suppose uniform clonal material, we assume that significant differences for nutrient requirements between categories will lead agronomists to propose adjusted fertiliser regimes based on planting material.

For the future, the objective should be for seed suppliers to provide the planter with maximum technical information about their seed characteristics, including specific requirements in terms of mineral nutrition.

In addition, such studies could lead breeders to identify highly efficient planting material for nutrient assimilation, and incorporate these properties in future breeding programes.

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