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Fertilizing for High Yield and Quality

THE OIL PALM

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1. Introduction

The oil palm is unsurpassed in its ability to intercept and transform solar energy into vegetable oil. Under optimal conditions of soil, climate and management plantation scale yields of over 8 m.t. of oil/ha/year have been achieved (Table 1). Palm oil production in the world and in the major producing countries is shown in Tables 2 and 3 while Table 4 contains data on international prices for some fats and oils.

Recent developments in clonal oil palm propagation suggest that the maximum yield potential is now somewhere between 12 to 16 tonnes oil/ha/year during the peak years of production (year 6 to 10 from planting).

As fossil energy resources continue to shrink, the oil palm of the future may not only provide a reliable source of cheap edible oil, but may also become an important raw material and source of energy for industrial use. For instance, palm oil is already widely used in the manufacture of environmentally attractive low phosphate detergents.

When planted together with legume cover crops, the oil palm simulates the rain forest itself by protecting the soil from erosion, constantly renewing the supply of surface organic matter, and maintaining low soil temperatures. By encouraging natural predators and good soil conditions, well managed oil palms require very little chemical control of pests and weeds. Furthermore, current research is unveiling new and potentially interesting methods of biological pest control.

Table 1. Yields of various oil crops

Crop	Yield (Kg oil per ha)	Palm kernel (Kg oil per ha)	Total (Kg oil per ha)
Cotton seed	190	–	190
Soya bean	380	–	380
Peanut	875	–	875
Coconut – Estate recorded	2690	–	2690
Coconut – Modern hybrids (potential)	4000	–	4000
Oil Palm – Malaysian average	3700	410	4110
Oil Palm – Malaysian recorded	8295	915	9210
Oil Palm – Potential (cloned palms)	14000	1.500	15000

Source: Adapted from *Bek-Nielsen [1977]*

Table 2. World palm oil production

Region	Country	Palm oil production (1000 t palm oil)	% of world total
World	–	9061	100
Africa	–	1586	17.5
	Angola	40	0.4
	Benin	40	0.4
	Cameroon	110	1.2
	Ivory Coast	235	2.6
	Gambia	55	0.6
	Ghana	45	0.5
	Nigeria	750	8.3
	Sierra Leone	44	0.5
	Zaire	170	1.9
	Others	97	1.1
Central America	–	143	1.5
	Costa Rica	58	0.6
	Honduras	72	0.8
	Others	13	0.1
South America	–	381	4.3
	Brazil	53	0.6
	Colombia	169	1.9
	Ecuador	116	1.3
	Others	43	0.5
Asia	–	6779	74.8
	China	205	2.3
	Indonesia	1370	15.1
	Malaysia	5033	55.5
	Philippines	41	0.5
	Thailand	130	1.4
Oceania	–	171	1.9
	Papua N. Guinea	156	1.7
	Solomon Islands	15	0.2

Source: FAO Production Yearbook [1988]

Table 3. Palm and palm kernel oil production from the major producing countries

	Production (1000 t)			Growth rate (%/year)	
	1970-72	1977-79 (average)	1985	1970-79	1978-85
Palm oil					
Malaysia	580	1860	4133	18.1	12.1
Indonesia	250	540	1177	11.6	11.8
Nigeria	580	670	269	2.1	-12.2
Ivory Coast	70	142	189	10.6	4.2
Papua New Guinea	7	80	123	41.6	6.3
Columbia	30	50	120	7.6	21.9
Thailand	–	9	110	–	43.0
China	130	180	97	4.8	-8.5
Others	573	609	703	0.9	2.1
World total	2220	4140	6921	9.3	7.6
Palm kernel oil					
Malaysia	60	180	640	17.0	19.9
Indonesia	30	50	94	7.6	9.4
Nigeria	140	140	174	0.0	3.2
Others	370	380	256	0.4	5.5
World total	600	750	1164	3.2	6.5

Source: FAO Production Yearbooks 1980-1986

On a per unit basis, a well managed stand of oil palms fixes more carbon dioxide than a tropical rainforest on the same site. Furthermore, over 25% of the harvested crop material can be returned to the field as a nutrient rich organic mulch in the form of empty bunches and factory sludge.

The oil palm is well suited to succeed rainforest after the extraction of timber, and can be very effective in transforming man-made savannah into a highly productive farming system.

From consideration of these factors, the oil palm can be viewed as an ecologically sound and attractive crop.

Unlike most other tree crops, the oil palm is capable of producing fruit throughout the year on a regular basis. Young palms produce approximately three fronds per month and as the palms increase in age the rate of frond production decreases to around 1.6 to 2.0 fronds per month. In the axil of each frond there is a flower bud capable of producing a harvestable fruit bunch. In a given environment, the extent to which this potential is realised depends largely on the amount of stress the oil palm tree is exposed to during the period from flower initiation the production of a ripe bunch, a period of approximately three and a half years. While many seasonally bearing tree crops require some stress (moisture, temperature, light, etc) to induce flowering and fruit set, the oil palm responds to any extended exposure to stress with a reduction in fruit production, while vegetative growth is little affected. Figure 1 attempts to show the effect of stress on the process from flower initiation to the production of a ripe bunch.

Table 4. International market price for some fats and oils (US$/ton, current prices)

Year	Palm	Soybean	Palm kernel	Coconut	Tallow
1970	250	290	366	319	207
1971	262	304	332	294	193
1972	218	243	220	190	179
1973	372	430	506	430	356
1974	674	832	1054	991	449
1975	435	563	408	390	340
1976	396	438	433	419	371
1977	530	576	620	582	421
1978	600	607	703	696	483
1979	654	663	967	998	595
1980	583	598	669	575	487
1981	569	506	588	566	471
1982	445	447	458	462	422
1983	501	527	709	735	423
1984	729	723	1037	1172	531
1985	510	581	567	625	427
Average 1970-76	484	521	602	590	397
Average 1976-85	552	567	675	683	463

Source: FAO Production Yearbooks 1980-1986

Note: Palm oil: Malaysian 5% bulk c.i.f. N.W. Europe
Soybean oil: Crude Dutch f.o.b. ex. mill
Palm kernel oil: Malaysian c.i.f. Rotterdam
Coconut oil: Philippines c.i.f. Rotterdam
Tallow: US c.i.f. Rotterdam

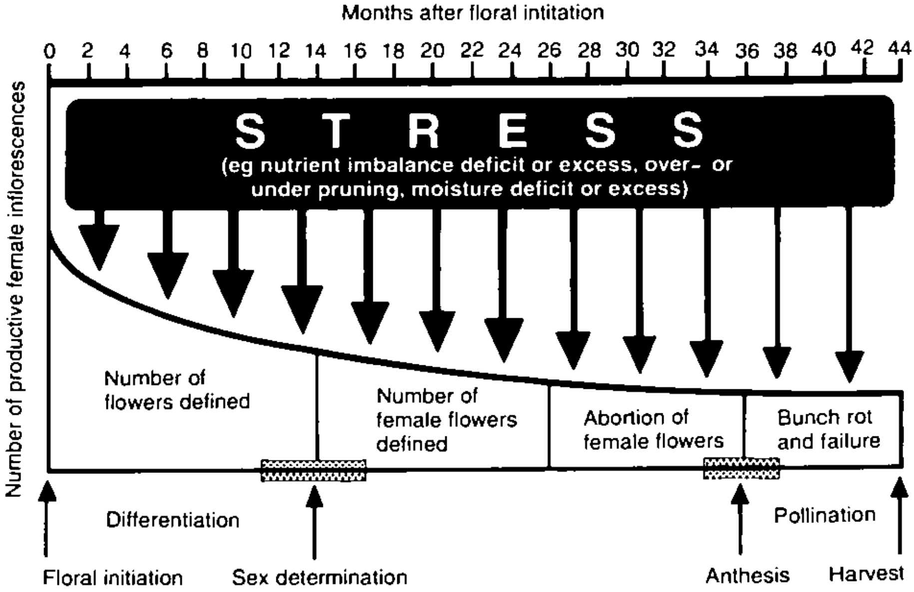

Fig 1. Effect of stress on the production cycle in oil palm

Major stress factors in oil palms are moisture (deficit or excess), light, temperature (extremes and fluctuations) and nutrition (deficit, excess, and imbalance). Where these stress factors are eliminated, minimized or controlled by appropriate management and agronomic techniques, a full stand of properly spaced oil palms is capable of producing yields of 40 to 50 tonnes of fresh fruit bunches per hectare (more than 12 tonnes of oil).An exellent 32 month old oil palm, entering the first full year of harvest is shown on Plate 1.

This bulletin focuses on the role of fertilizer as a major factor contributing to high sustainable yields. Since the effect of fertilizer largely depends on interactions, no single production factor can be seen in isolation. Optimal response to fertilizer application therefore requires a holistic approach involving the management and manipulation of these interactions to provide a productive balance in which stress is minimized so that the genetic potential of the tree stand is expressed to the fullest extent.

2. The oil palm environment

2.1. Climate

More than 95% of the world's oil palms are grown within the range of 10° north and south of the equator. It is worth noting that the oil palm has performed best in areas outside its place of origin, where climate is a major limiting factor to high yields. There are four major climatic components affecting the performance of oil palms:

* Rainfall
* Solar radiation
* Temperature
* Wind

2.1.1. Rainfall

Perhaps the most commonly occurring limiting factor in oil palm is moisture stress.

To develop its full yield potential, the oil palm requires an adequate year round supply of moisture. The ideal rainfall regime is probably between 2500-3500 mm per year, evenly distributed with no month having rainfall below 120 mm. However, desirable rainfall patterns must always be related to the soil's water relations (retention and drainage). Adequate rainfall is an important factor in the fruit ripening process, and for the development of a high oil to bunch ratio.

Prolonged water stress tends to cause a sharp decrease in the number of female inflorescences and an increase in male flowers. A drop in yield due to change in the sex ratio usually occurs 19 to 22 months after a period of prolonged drought. This corresponds with the interval between floral initiation and flower emergence. Extended drought can result in the abortion of female flowers.

The more pronounced seasonal fruit production in West Africa is accounted for in the prolonged and regular dry season which prevails there. However, the oil palm remains an important crop in sub-optimal climates in Benin where the annual rainfall is less than 1200 mm, since the oil palm even under these conditions still out-yields other oil-producing crops.

In a location in the Ivory Coast, suffering from long periods of drought stress, irrigation raised yields from 7.5 to 26.0 tonnes fresh fruit bunches per hectare per year *(IRHO [1962])*.

However, once moisture stress has been eliminated, fertilizer applications must be increased in order to exploit and sustain the higher yield potential.

In contrast, very high sustained yields (27-30 tonnes FFB/ha/ year) have been obtained by smallholders in West Sumatra in an area with free draining soils receiving rainfall in excess of 4000 mm per year. Very often, such high rainfall is associated with prolonged periods of cloud cover, resulting in reduced solar radiation. In West Sumatra most of the rain falls in the late afternoon and in the night, thus ideally combining high solar radiation with excellent moisture availability.

2.1.2. Solar radiation

After rainfall, solar radiation is the second most important climatic component, although exact requirements in terms of either hours of sunshine or total radiation are not clearly defined. Sunshine hours of over 2000 hours/year are desirable provided that such an amount of sunshine is not associated with drought and excessive temperatures.

The importance of solar radiation is clearly shown by the effect on yields of thinning adult stands. *Bachy [1965]* showed that the six palms surrounding a vacant point can compensate for up to 90% of the missing palm's production by increases in bunch number and bunch weight. This is borne out by a plantation in the Solomon Islands where yields returned to normal only four years after the destruction of 20% of trees during Cyclone Namu.

Corley [1976a] showed that the gross photosynthesis of leaves in the top of the canopy of 8-10 year old palms is about 16-17 $g/m^2/day$, whereas leaves in the bottom of the canopy have a photosynthetic rate of only 4.6 $g/m^2/day$. With the respiration rate being more or less constant this means that net respiration of young leaves is 13 g but only 0.5 g with old leaves and an excess of old leaves can result in net loss of energy (Table 5). Proper thinning can dramatically increase the net photosynthesis of older leaves.

Clearly the desirable leaf number changes as the oil palm stand becomes older. However, by careful manipulation and management of, in the first place planting density, and later pruning and thinning, near optimal leaf area conditions can be maintained throughout the oil palm's productive life. Thus a high planting density of 143 palms/ha with minimal pruning in the early years allows the fast development of an optimal leaf area index. Later, the stand can be thinned and the pruning policy modified to optimize canopy conditions when inter palm competition becomes the limiting factor.

As will be explained later the leaf area interacts strongly with nutrition and maintenance of an optimal leaf area is a key factor in efficient fertilizer use in oil palms.

Table 5. Estimated total canopy photosynthesis (CO_2 uptake)

Leaves	Gross photo-synthesis* ($g/m^2/day$)	Respiration** ($g/m^2/day$)	Net photo-synthesis ($g/m^2/day$)	Total leaf area ($m^2/palm$)	Total net photo-synthesis (kg/palm/day)	Total gross photo-synthesis* (kg/palm/day)
1-8	16.9	3.9	13.0	84	1.09	1.42
9-16	16.1	4.0	12.1	82	0.99	1.32
17-24	11.8	4.4	7.4	80	0.59	0.94
25-32	8.7	4.6	4.1	76	0.31	0.66
33-40	4.6	4.1	0.5	72	0.04	0.33
Total				394	3.02	4.67
Carbohydrate equivalent, t/ha/year (at 138 palms/ha):					104	160

* assuming respiration at dark rate troughout 24 hrs.

** from extrapolation of light response curves.

Source: *Corley [1976a]*

2.1.3. Temperature

Being essentially a crop of the lowlands in the humid tropics, the oil palm is sensitive to both low and very high temperatures . The optimum temperature range for oil palms is between 22° and 32° C, a range which prevails over most of the humid tropics. The growth rate of young seedlings is totally inhibited at temperatures of 15°C and below, whilst growth rate is respectively three and seven times as rapid at 20°C and 25°C than it is at 17.5°C *(Henry [1957])*.

Low minimum temperatures are found where the elevation exceeds 200 m, and there are reports from Sumatra that palms planted above 500 m come into bearing up to one year later than palms in the lowlands, with correspondingly reduced early yields.

2.1.4. Wind

Unlike the coconut palm, the oil palm cannot withstand strong winds. This is on account of the oil palm's larger and softer crown. It is therefore not advisable to plant oil palms in areas frequented by tropical storms (typhoons and cyclones). Light winds, especially during periods of intensive solar radiation are desirable as they promote both transpirational and convectional cooling of the leaf. Wind damage can be accentuated by the indiscriminate use of amine based herbicides.

2.2. Soils

Good yields of oil have been obtained from palms grown over a wide range of soils. However it is essential that appropriate techniques of land clearing and preparation, drainage, and soil conservation are employed to optimize soil water relations, conserve surface organic matter, and ameliorate soil structure problems during the establishment phase.

Since each soil has its own peculiarities, it is important to apply a parcel of techniques specifically tailored to each site. For example the over-draining of flooded acid sulphate soils can induce toxic acid conditions. In this case, the emphasis should be on soil water management rather than drainage alone.

Ng [1968] suggested certain criteria to assess soil suitability for oil palms (Tables 6 and 7).

The oil palm has a relatively shallow root system with most of the active roots found in the upper 30 cm of soil *(Gray [1969])*. In some coarse textured well-drained soil's poor water holding capacity and poor nutrient status can be partly compensated for by better rooting.

Compared with annual crops and even with most dicotyledonous tree crops, the root system is coarse and relatively inefficient *(Tinker [1976])*. To maintain adequate nutrient supply to the palm the nutrient concentration in the soil must be higher than is required for most crops. *Tinker [1974]* calculated that in a moist sandy loam, which he studied, the minimum initial concentrations in the soil solution would need to be about 0.7×10^{-6} m for potassium, 3×10^{-6} m for phosporus and 1.5×10^{-5} m for magnesium. To maintain an adequate concentration of nutrients at the root surface - which is needed for uninterrupted and adequate uptake - a much higher concentration in the soil solution would be required. Very few soils can therefore supply the nutrient needs of high yielding oil palms and that is why oil palms do tend to respond to fertilizer application even on tropical soils considered to be comparatively fertile.

However, the full potential benefit from applied fertilizer can only be realised where soil management techniques are deployed to ensure the maximum retention of applied nutrients in an available form.

Table 6. Major criteria used in assessing soil suitability for oil palms

Property	Grade Favourable	 Marginal	 Unfavourable
Terrain (slope)	< 12°	12-20°	> 20°
Effective soil depth in relation to impenetrable sub-soil layer or permanent water table	> 75 cm	40-75 cm	40 cm
Texture	loam or heavier	sandy loam	loamy sand or sand
Structure and constistency	strongly developed, friable to moderately firm	moderately developed and firm	weak or massive and extremely firm
Laterite	nil	fragmental 15-30 cm thick	fragmental > 30 cm thick or massive
pH	4.0-6.0	3.2-4.0	< 3.2
Peat layer (thickness)	0-0.6 m	0.6-1.5 m	> 1.5 m*
Permeability	moderate	rapid or slow	very rapid or very slow

* Newly developed or perfected technology (e.g. compaction of the peat layer, hole-in-hole for planting) has permitted the establishment of very productive oil palm stands even on deep peat. The suitabilitiy grading for peat therefore needs revision.

Source: Adapted from *Ng [1968]*

Table 7. Soil classification based on the criteria of suitability

Classification	Criteria
Highly suitable	Soils possessing all scheduled properties witbin favourable grade.
Moderately suitable	Soils possessing not more than two properties in marginal grade.
Marginal	Three or more properties under marginal grade plus one property in unfavourable grade.
Unsuitable	Two or more properties under unfavourable grade.

3. Planting material and nursery selection

The yield potential for the oil palm's 20 year productive life is largely defined in the first 12 months: from seed planting in the nursery to field planting. A major precondition for the development of any tree crop is the provision of good quality uniform planting material selected for vigour and correctly planted at the appropriate planting density. While mistakes in upkeep can be corrected, negligence in nursery selection has a detrimental effect on yields throughout the productive life of the stand and cannot easily be corrected.

Current seed production is largely based on crossing two tree types differing in a single factor regulating the thickness of the shell and pericarp. The two types are the thick shell/thin pericarp *dura* and the shell-free/thick pericarp *pisifera*. Shell thickness is controlled by a single gene. Crossing the two types produces the thin shelled *tenera*. High quality hybrid seed is currently produced in West Africa, Malaysia, Indonesia and Papua New Guinea, but most of the current commercially available crosses still lack uniformity. Off-types can amount to up to 25% of the population, and have to be identified and removed (culled) in the nursery. *Woo et al. [1987]* showed that having a mere 2.5 "runts" per hectare results over the twenty year economic life-span of the palms in a loss of approximately 450 M$/ha (1987 prices) versus savings (by not culling runts) of M$ 7.5/ha, a savings/loss ratio of 1 to 60.

The significance of the quality of planting material is illustrated in Figure 2, which is based on the results from field scale plantings where seedling quality was the main modifier of final yield. Discounting the maiden crop in year 3, the difference in yield in year 4 between the highest (81/348) and the lowest yield (80/487) was 11 tonnes FFB/ha. This difference has accumulated to 21 tonnes FFB/ha by year 5 and will continue to accumulate throughout the life of the stand. Unfortunately such losses remain invisible to most, as is the sheer waste of fertilizer applied to unproductive or sterile palms.

Most of the currently available hybrid seed material shows considerable variability between seed batches. Therefore named crosses should always be planted in separate lots to allow culling within each "type". Otherwise certain crosses with, for instance, a "dumpy" habit may be mistakenly removed as stunted or lacking vigour. In most plantations more than 50% of the yield comes from less than 30% of the population, though not all of this variation will be due to genetic factors. Much greater uniformity is to be expected once clonal material is introduced, but as long as seedlings are raised from seed, a good nursery and ruthless culling are the corner stones for the development of high yields and efficient fertilizer utilization.

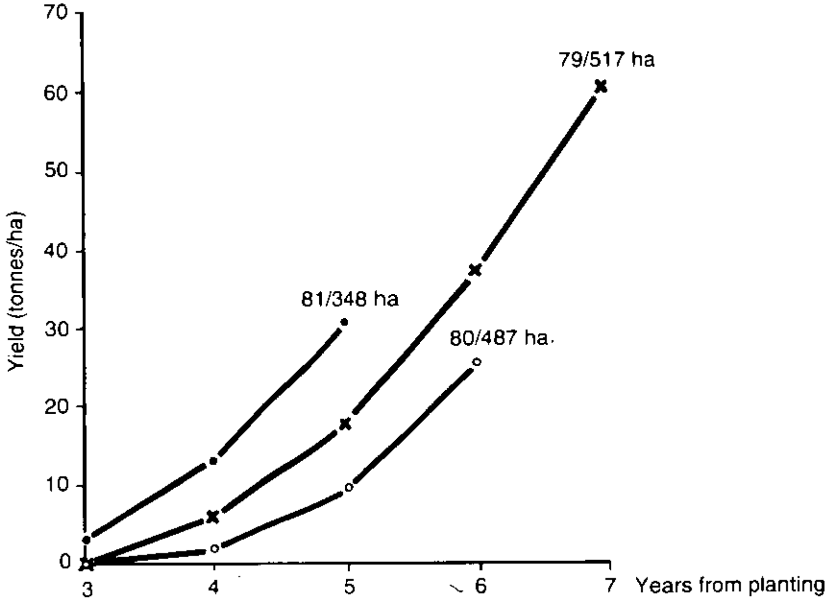

Fig 2. Effect of seedling quality on cumulative yields of 3 plantings

4. Nutrition

4.1. Nutrient uptake, immobilization and removal

Depending on the type of planting material, climate, spacing, soil, ground cover and other environmental factors, the nutrient demand of oil palms can vary over a wide range. As shown in Table 8 the nutrient demand of oil palms consists of three components:

1. Nutrients removed with the harvested crop (fresh fruit bunches or FFB)

2. Nutrients immobilized in plant tissue.

3. Nutrients recycled with pruned leaves, male flowers and leaf-wash

Table 8. Nutrient removal, immobilization and recycling in adult oil palms in Malaysia[1] and Nigeria[2] (Kg per palm per year)

	Malaysia (Yield 24 t FFB/ha)				Nigeria (Yield 9.7 t FFB/ha			
	N	P	K	Mg	N	P	K	Mg
a) Removal with harvested fruit	0.49	0.88	0.63	0.14	0.20	0.04	0.23	0.03
b) Immobilized in palm tissue	0.27	0.022	0.47	0.072	0.18	0.024	0.11	0.104
c) Nutrients recycled	0.53	0.076	0.69	0.19	0.63	0.073	0.38	0.25
Total nutrient uptake	1.29	0.18	1.79	0.40	1.01	0.14	0.72	0.38
Removal in % of total uptake	38	44	35	35	20	29	31	8
Total uptake/ha (148 palms/ha)	191	27	265	59	149	21	107	56
Uptake per ton of FFB, kg	8.0	1.1	11.0	2.5	15.5	2.2	11.1	5.8

Source: [1] Malaysia: *Ng and Tamboo [1967]*
[2] Nigeria: *Tinker and Smilde [1963]*

As shown in Table 8 nutrient uptake and nutrient removal is much higher in Malaysia than in Nigeria. The efficiency of nutrient utilization (nutrient uptake per tonne of FFB)is also much higher in Malaysia than in Nigeria. The distribution of absorbed nutrients among the different plant components is shown in Table 9. The average content of one tonne of FFB is given in Table 10.

Figure 3 shows nutrient off-take of oil palms over time in an optimal environment, where soil conditions and climate are relatively non-limiting. As could be expected, nutrient off-take is rather low in the first year when the palms are suffering transplanting shock and require time to establish an effective root system. From the fifth year onwards, annual nutrient uptake tends to stabilize and decreases as palms reach the age of ten years and above. Total dry matter production in the second year is estimated to be eight times higher than in the first. On the basis of extensive studies, *Tan [1976, 1977]* estimated the nutrient requirement of palms of different age as shown in Table 11.

These findings about the early, steep increase in the nutrient demand of high yielding oil palms are very important in the formulation of fertilizer policies, especially in the immature phase.

Table 9. Nutrient uptake and distribution of nutrients among different plant components (148 palms/ha)

Component	N		P		K		Mg		Ca	
	kg	%	kg	%	kg	%	kg	%	kg	%
1. Net cumulative vegetative matter	40.9	21.2	3.1	11.9	55.7	22.2	11.5	18.8	13.8	13.9
2. Pruned fronds	67.2	34.9	8.9	34.2	86.2	34.2	22.4	36.5	61.6	61.9
3. Fruit bunches (25 tonnes)	73.2	38.0	11.6	44.6	93.4	37.1	20.8	33.9	19.5	19.6
4. Male inflorescence	11.2	5.9	2.4	9.3	16.1	6.4	6.6	10.8	4.4	4.6
Total	195.5	100	26.0	100	251.4	100	61.3	100	99.3	100

(26.0 kg P = 59.5 kg P_2O_5, 251.4 kg K = 302.8 kg K_2O)

Source: *Ng et al. [1967[*

Table 10. Nutrient content of one ton of fresh fruit bunches

Kg					Gramme				
N	P	K	Mg	Ca	Mn	Fe	B	Cu	Zn
2.94	0.44	3.71	0.77	0.81	1.51	2.47	2.15	4.76	4.93

Table 11. Nutrients required by palms of different ages (kg/ha)

Age period (total/year)	N	P	K	Mg	Ca
0-3	39.8	6.1	55.4	7.4	12.9
3-9	191-267	32-42	287-387	48-67	85-114
0-9 (cumulative)	1231-1720	204-272	1850-2487	314-423	531-721

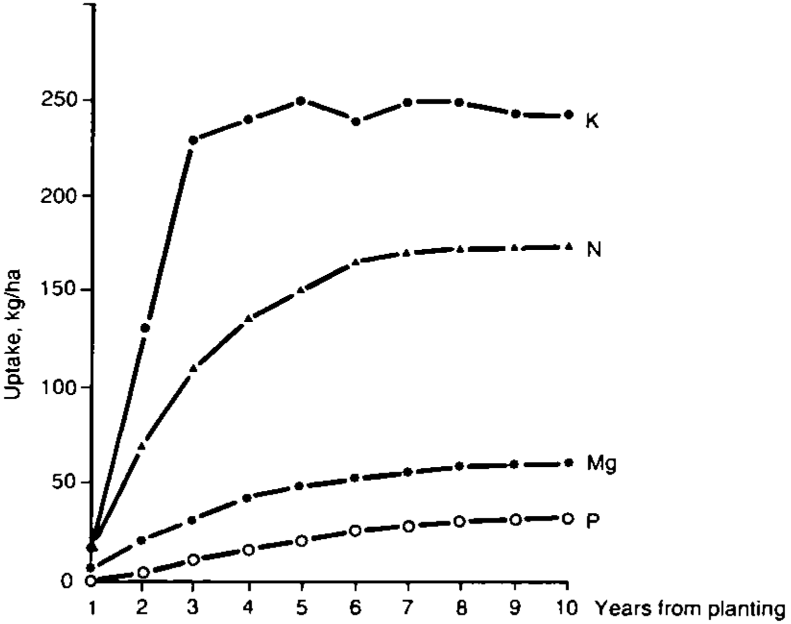

Fig 3. Nutrient uptake of oil palms up to 10 years from planting (Ng [1977])

4.2. Nutrients and nutrient sources

The general functions of the major and minor nutrients are sufficiently known and have been described in detail in several textbooks *(see Mengel and Kirkby [1987]).* In this chapter, the discussion will be limited to the more specific role of nutrients as observed in the oil palm. For a more detailed account of the physiological effects of individual nutrients, the reader is referred to the work of *Corley [1976b]* and *Rajaratnam [1976].*

The discussion of effects and functions of individual elements in isolation always entails some danger, because all essential elements are intricately involved in physiological processes that lead to the final product the palm is grown for: it's oil.

4.2.1. Major nutrients

4.2.1.1. Nitrogen (N)

Effect
N primarily affects leaf area, leaf colour, rate of leaf production and net assimilation rate. There is usually a good response to nitrogen as long as the leaf area index (LAI) is below 5. For this reason young palms tend to respond very well to N application. With old palms a response to N may be absent if the LAI is above 6, indicating strong inter-palm competition for light. In such cases, thinning might be a precondition to get a response to N.

Excess N
Excess N in relation to other nutrients can depress yields and render palms more susceptible to disease and attack from leaf-eating insects (caterpillars, bagworms). Application of N to palms affected by crown disease prolongs the recovery period and may predispose the affected palm to spear rot or even lethal bud rot. Infected trees should not receive any nitrogen until they have produced at least 25 normal leaves.

N deficiency
N deficiency is common in young palms grown on shallow, sandy or poorly drained soils (Plate 2). In such cases, the correction of poor drainage is an essential prerequisite to obtaining a good response to nitrogen fertilizer. N-deficiency can also be induced or aggravated by grasses, especially *Imperata cylindraca* (alang-alang). A ground cover dominated by *Mikania cordata* also tends to suppress N in oil palm leaves. Grasses and possibly also *Mikania* may sharply reduce non-symbiotic N fixation taking place on the surface of active oil palm roots.

Adequate nitrogen supply is particularly important up to year 5 or 6 in the field when proper N fertilizer application is essential for an economic oil palm operation. Well established ground covers can contribute up to 300 kg N/ha/year. However, high nitrogen fixation by cover crops depends initially on an adequate supply of phosphate and a small investment in the application of a good reactive rock phosphate during cover crop establishment will pay profitable dividends in increased nitrogen fixation.

N sources

The preferred source of nitrogen for oil palms is ammonium sulphate, but due to lower price and availability, urea is gradually becoming the dominant N fertilizer. Other sources of significance include ammonium chloride and ammonium nitrate.

N-rates

Amounts applied range from 1.5 to 8 kg/palm of ammonium sulphate or its equivalent. N application rates depend mainly on the age of the stand but also on the yield potential which in turn is affected by the climate (solar radiation, amount and distribution of rainfall) and soil type. N rates must always be adjusted to leaf area. N rates should therefore be higher where planting densities are low (112 - 128 palms/ha), and are usually lower when planting densities are high (138 - 148 palms/ha).

N-placement

With young palms N should be spread evenly over the weeded circle. Ideally application should be timed to follow circle weeding rounds to minimize competition from ground vegetation. In old palms inter-row application is also possible and often preferable provided there is no serious competition from the ground vegetation. In no case should N be applied in heaps or in a narrow band around the base of the palm as this practice will increase N losses and may cause severe damage to the roots .

Timing of N application

Since nitrogen can be easily lost through leaching, surface run-off and volatilization, timing of N application is much more critical than that of other nutrients.

To minimize N losses due to volatilization, N (especially in the form of urea) should only be applied at times of assured rainfall. Urea should never be applied on dry soils. Higher rates of N (more than 1 kg of urea/palm) should be applied as split doses and in areas with an extended dry season the last N application should be at least 3-4 months before the onset of the dry season.

Optimum leaf N concentration

Depending on age, planting density and climate, the optimum leaf concentration can range between 2.4% and 3% N in dry matter. In young palms an N concentration below 2.5 and in old palms of less than 2.3% indicate deficiency and suggest the need for a corrective N application.

4.2.1.2. Phosphorus (P)

Effects

Palms deficient in P have a low growth rate, short fronds, small trunk diameter and small bunches. Oil palms are usually very efficient in utilizing both soil and fertilizer P, probably due to very effective mycorhyzza associations.

Excess

Excess soluble P (applied TSP or DAP) can on very sandy soils induce deficiencies of copper and zinc. This has been observed on a plantation in north Sumatra, Indonesia.

P-deficiency

In contrast to most other nutrients , leaves deficient in P do not show specific symptoms, other than reduced frond length. Trunk diameter and bunch size of P deficient palms are reduced as well . Pyramiding in palms may be associated with the progressive depletion of soil phosphorus when available phosphate present in the surface soil organic matter is lost through erosion. P deficient sites may be indicated by the predominance of grasses (particularly alang-alang) over legumes (difficulty in establishing a good legume cover) and a purplish tint showing on many of the grass blades.

P-sources

For young palms up to year 3 in the field, water soluble sources such as TSP, DAP and quality NPK compounds or highly reactive rock phosphates may be used. For older palms, reactive rock phosphates are more appropriate.

P-rates

The P-rates used for oil palms range from 0.5 - 2.0 kg of TSP or its equivalent per palm per year. As most soils where palms are grown are acidic and highly deficient in P, it is always recommended to give a one-time blanket application of P in the form of reactive rock phosphate for cover crop establishment. Rates used range from 200-500 kg of reactive rock phosphate per hectare. Phosphate applied in this way is cycled by the cover crop and deposited at the soil surface in the form of leaf litter.

P-placement

For young palms, P should be applied over the circle, including its outer rim. As the root system develops and the canopy closes, P utilization is better when applied in the inter row.

Timing of P application

P cannot be lost due to volatilization or leaching. The only way applied P can be lost is through surface erosion. Unlike N, timing of P applications is not critical and not very dependent on season or weather conditions. However absorption of applied P fertilizer and response to P is highly dependent on adequate rainfall.

Optimum leaf P concentration

The optimum leaf concentration ranges between 0.15 to 0.19% P. Concentrations below 0.13% P indicate serious deficiency especially if found in combination with high N concentrations. The close interdependency of N and P was studied by *Tampbulon et al [1990]* who elaborated a "critical curve" for P levels depending on N content. This relationship appears to have universal application and is defined as:

$$P\% = 0.0487\ N\% + 0.039$$

4.2.1.3. Potassium (K)

Effects

K increases drought and disease resistance of palms and affects bunch size and bunch number. On many soils, especially on sandy soils and peat soils, lack of K is usually the largest single nutritional factor affecting yield.

K-deficiency

A considerable variety of symptoms has been associated with K-deficiency, with differences in symptoms caused by environmental and genetic factors.

The common symptoms are as follows:

a. Confluent orange spotting, also sometimes referred to as "speckled bronzing" or "speckled yellows"

Orange spotting is the most common symptom of K deficiency (Plates 3 and 4). It starts with the development of pale yellow, irregularly shaped spots along the pinnae of older fronds in the canopy. As the symptoms become more severe with time, the spots turn orange and in severe cases fuse to form compound lesions of a bright orange colour. At a more advanced stage, brown necrotic spots appear in the centre of the orange spots and marginal necrosis develops along leaflets, starting from the distal end.

Occasionally single palms can be found showing very bright orange spotting while all surrounding palms appear to be normal. In such cases the symptoms are most likely due to a genetic defect rather than to K deficiency.

b. Diffuse yellowing or "mid-crown yellowing".
Symptoms of diffuse yellowing occur typically in K-deficient, low pH sandy soils or on peat, especially during or after periods of serious water stress. Pinnae in the lower to middle sector of the canopy become pale and then turn yellow to orange yellow. In severe cases older fronds suddenly desiccate and die.

c. Orange blotch or Mbawsi symptom.
The first symptom of orange blotch is the appearance of the large elongated diffuse olive-green blotches on pinnae of older fronds, showing up in pairs, half way along the pinnae. With increasing age and severity the blotches turn bright yellow to orange and eventually brownish yellow before the pinnae die.

d. White stripe.
White, pencil-like stripes occur on both sides of the mid-ribs of pinnae, usually in the middle to upper sectors of the crowns of young 3 to 6 year old palms. Though not a straight forward symptom of K deficiency white stripe is most likely caused by a nutrient imbalance involving excess N in relation to K, and probably a lack of boron.

K-deficiency and diseases
K-deficiency has been associated with increased disease incidence *(Prendergast [1957], Turner [1981], von Uexkull [1982])* such as vascular wilt *(Fusarium oxysporum)* (Figure 4), Cercospora leaf spot and Ganoderma basal stem rot. Bunch failure and plant failure are two physiological disorders that sometimes appear to be linked to inadequate K supply *(Turner [1981]).*

Excess K
Excess K may lower the oil content in the fruit and may induce boron deficiency in acid soils, low in boron.

K-sources
Potassium chloride (KCl) is the sole K-source of significance. Potassium chloride has the added benefit of supplying chloride, an element beneficial and often deficient in oil palms. Bunch ash can be substituted for KCl at a rate of 3:2, and being strongly alkaline has an ameliorative effect on strongly acid soils. Bunch ash is highly hydroscopic so that the

nutrient content, on a fresh weight basis decreases rapidly during storage. It should therefore always be applied fresh. Empty fruit bunches are another good source of potassium when applied as a mulch layer in the inter-row. 30 tonnes empty fruit bunches spread in the inter-row can supply the equivalent of 180 - 220 kg KCl/ha.

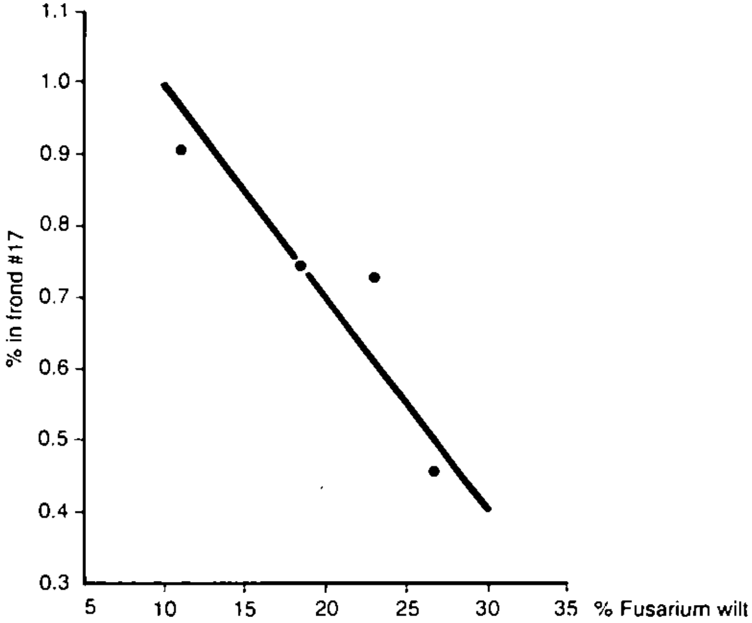

Fig 4. Relation between leaf K and the occurence of vascular wilt in oil palm
(after Turner [1981])

K-rates range from 1 to 5 kg of KCl/palm/year, depending on age of palms, soil type and yield potential. Like N, K response is often absent if there is strong inter-palm competition for light.

K-placement
Unlike N (especially urea) K application is not weather-dependent. K can be safely

applied on dry soil. K losses can only occur through leaching and through surface run-off. Such losses can be minimized by distributing K evenly over the entire weeded circle for young palms and broadcasting KC1 in the inter- row area or over the frond heaps in older palms.

Optimum leaf K-concentration

In contrast to most other elements the pinnae (leaflets) are not a very good reference tissue to estimate the K-nutritional status of oil palms. Optimum K concentrations can vary over a wide range, depending largely on such factors as age, the water regime, spacing (inter-palm competition for light) and other factors. For most soils "normal" K values range between 0.9 to 1.3. *Teoh and Chew [1988]* suggested that the rachis was a far more sensitive reference tissue. They propose following classification of the K status based on rachis tissue from frond No. 17:

Classification	% K in rachis tissue
High	> 1.60
Adequate	1.31 - 1.60
Marginal	1.01 - 1.30
Low	< 1.01

4.2.2. Secondary nutrients

4.2.2.1. Magnesium (Mg)

Magnesium deficiency

Magnesium deficiency has been found in all regions where oil palms are grown. It is a most frequent problem in light textured soils and in acid soils, where the topsoil has been eroded.

Mg-deficiency is expressed as a chlorosis of older leaflets that exhibit a bright orange-yellow colour (Plate 5). For this reason Mg- deficiency has been named "Orange frond". Early symptoms of Mg- deficiency are olive-green or ochre patches that appear close to the tip of older pinnae, most exposed to sunlight. With increasing severity of the symptom the colour changes to bright yellow and deep yellow and eventually the affected leaves desiccate.

Mg-deficiency symptoms are always most pronounced on leaflets exposed to sunlight and absence of chlorosis on pinnae or parts of pinnae protected from direct exposure to sunlight is a clear diagnostic feature. Mg-deficiency can be induced or accentuated by heavy potash dressings. Many palms appear to be genetically pre-disposed to Mg-deficiency.

Mg-sources

Kieserite (Mg $SO_4.H_20$), containing 26% available Mg0 is the main Mg source for oil palms. Other sources include sulphate of potash, magnesia and dolomite. While dolomite can be used for maintenance on acid soils, it is too slow-acting for the correction of acute deficiencies, especially on high pH soils.

Mg-rates

For the correction of acute Mg-deficiency, a one time application of 2 to 5 kg kieserite per palm is recommended in split doses. For maintenance, annual dressings of 0.5 to 1.5 kg per palm are usually sufficient.

Mg-placement

With young palms kieserite should be applied over the weeded circle. However kieserite is more effectively utilized by older palms when applied in the inter-row over the cut frond heaps. Dolomite should always be spread evenly over the inter-row area and not over the weeded circle.

Mg-timing

Timing of Mg application is not critical, but where heavy rates are needed to correct acute deficiency, the Mg-applications should precede the application of KCl.

Optimum leaf Mg-concentrations

The optimum range is probably between 0.30 and 0.40 %, and Mg- deficiency is indicated if the Mg concentration in frond 17 tissue falls below 0.20%.

4.2.2.2. Calcium (Ca)

Although good responses to lime application have been frequently observed on acid and peat soils, it is not clear whether this response was due to a direct Ca-effect or due to an indirect effect of making trace elements and N and P more readily available.

Outright Ca-deficiency has so far not been reported in oil palms and the largest benefit from applied Ca (lime or dolomite) is probably due to better growth of legume cover, higher N-fixation and improved P availability.

4.2.2.3. Sulphur (S)

S-deficiency has not yet reached levels of significance in any of the major oil palm growing areas. S-deficiency has been identified in young palms on poorly drained acid clay land formerly covered by a savannah type of vegetation *(Cavez et al. [1976])*. Here an application of pure sulphur may be called for particularly where urea is the source of N used.

In the early stages, S-deficiency resembles N deficiency. S- deficient pinnae are pale and small and as the deficiency becomes more acute, small brown necrotic spots may appear. *Cavez et al. [1976]* suggest that S-deficiency may increase the incidence of *Cercospora* infection. Ammonium sulphate and kieserite are currently the main S sources for oil palms.

4.2.2.4. Chloride (Cl)

Chloride has recently been found to be essential and highly beneficial to coconut and oil palms in concentrations that places it squarely into the range of the secondary nutrients *(Ollagnier et al. [1971], Ollagnier [1973])*.
No definite deficiency symptoms have been identified so far.

Chloride deficiency severely affects the water economy of the palms *(von Uexkull [1972], von Uexkull [1990])*. Chloride might also be involved in insect and disease resistance of oil palms.

Potassium chloride (KCl) is the main chloride source for palms. In high K-soils ammonium chloride can be used as an efficient alternative source.

The optimum Cl concentration in the dry matter of frond No. 17 tissue is in the range of 0.45-0.6 % and big responses to Cl application can be expected where the Cl concentration is below 0.2 %.

Although Cl is highly mobile, properly fertilized palms seem to be able to maintain satisfactory Cl concentrations in their foliage, even if no further Cl is applied. Cl-uptake and response to applied Cl by deficient palms is very fast.

4.2.3. Micronutrients

4.2.3.1. Boron (B)

Among trace elements only B is of general significance. The main morphological symptoms of boron deficiency involve abnormalities in leaf development such as "hooked leaf", "little leaf", "fish- bone leaf" and "blind leaf" (Plate 6). B-deficient leaves are not only misshapen and wrinkled, but they are also very brittle and dark green. The earliest symptom of B-deficiency is the shortening of younger leaves *(Rajaratnam [1976])* giving the palms a "flat- top" appearance .

"Fish-bone" like symptoms, resembling B-deficiency can also be induced by a bacterium of the genus Erwinia that has been found to be the cause of the "Bud-rot, little-leaf" disease *(Duff [1963]). Rajaratnam and Law [1975]* observed that the severity of red spider mite attack was accentuated by B-deficiency. A detailed description of disorders related to B is provided by *Turner [1981[*. B-deficiency can be accentuated by heavy N, K and Ca application. The B demand of palms has been increased as a result of better pollination due to the introduction of the pollinating weevil *Elaeidobius kamerunicus.*

B-sources
The main sources of B are the various forms of sodium borate (such as $Na_2B_4O_7 \cdot 10H_2O$ or $Na_2B_4O_7 \cdot 5H_2O$).

B-rates
Borate applications have become standard in young palms, starting with 50 g borate per palm in year 1 and increasing to 100 - 200 g per palm per year up to year 4 - 6. With very high yielding palms and under a very high fertilizer regime, B application may have to be continued on a regular basis even for older palms.

Optimum leaf B concentration
This appears to be in the range of 15 - 25 ppm.

Placement of B
Boron should be applied over the weeded circle, close to the stem. Axillary application, though effective, is not recommended as it may result in uneven distribution of B in the palm and can cause B-toxicity.

4.2.3.2. Copper (Cu)

Until recently Cu deficiency was believed to be restricted to peat soils where it has become known as "mid-crown chlorosis" since it was described by *Ng and Tan [1974]* and *Ng et al. [1974]*. Since then Cu deficiency has been identified in an area of over 20000 ha of very sandy soils in the province of Riau in Sumatra, where the symptoms already occur in the nursery. The symptoms observed there closely resemble those of "mid-crown chlorosis" as reported from peat soils.

Copper deficient plants are severely stunted. During the early stages of the disorder chlorotic specklings start to appear on the youngest open frond. With increasing severity, new fronds become increasingly shorter. Affected pinnae turn yellow starting from the distal end, followed by necrosis and desiccation.

Copper deficiency on mineral soil can be easily corrected by a one-time application of 50 to 100 g of copper sulphate per palm. Amelioration of "mid-crown chlorosis" is more difficult in palms grown on peat soils where Cu absorption through the root system is very inefficient.

Cheong and Ng [1976] report recovery in frond length and colour 4-6 weeks after palms were sprayed with a 200 ppm Cu solution. Four months after the first application the length of frond 1 of moderately affected palm was comparable with that of normal, healthy palms.

Soil application, though effective, took a longer time and to be effective, the dosage applied has to be considerably higher on peats than on mineral soil (about 500 g $CuSO_4$ on peat vs 50 - 100 g on sandy mineral soil).

Wanasuria and Gales [1990] observed that Cu deficiency on a mineral soil was exacerbated by high rates of N and P application, whereas high rates of KCl had a beneficial effect on the Cu nutrition of the palm (Table 12).

The optimum leaf concentration of Cu appears to be in the range from 5-8 ppm. A Cu concentration below 3 ppm indicates deficiency.

4.2.3.3. Zinc (Zn)

Though Zn deficiency was thought to be marginally involved in "peat yellows" for some time *(Turner [1981])* more recent work by *Singh [1988]* showed that zinc is a primary factor in this disorder. Peat yellows could be corrected by 2 yearly foliar application rounds with a solution containing 1000 ppm Zn. Soil application and trunk injection have proved to be ineffective. Application of zinc in trials improved vegetative growth and, depending upon the severity of peat yellows, increased FFB production by 12-78% (Figure 5).

Table 12. Effects of increasing rates of ammonium sulfate (N), triple superphosphate (P), and muriate of potash (K) fertilization on incidence of Cu-deficiency and on leaf Cu-concentration

All treatment combinations	Percentage of incidence of Cu deficiency	Leaf Cu concentration (frond 1) (ppm)
Effects of nitrogen: at any rates of P and Mg		
N_0K_0	0	7.3
N_1K_0	5	4.6
N_2K_0	21	3.1
Effects of phosphorus: at N_1 and N_2 and at any rates of Mg		
P_0K_0	9	4.5
P_1K_0	24	4.1
P_2K_0	34	2.9
Effects of potassium: at any rates of P and Mg		
N_2K_0	21	3.1
N_2K_1	0	4.5
N_2K_2	0	4.7

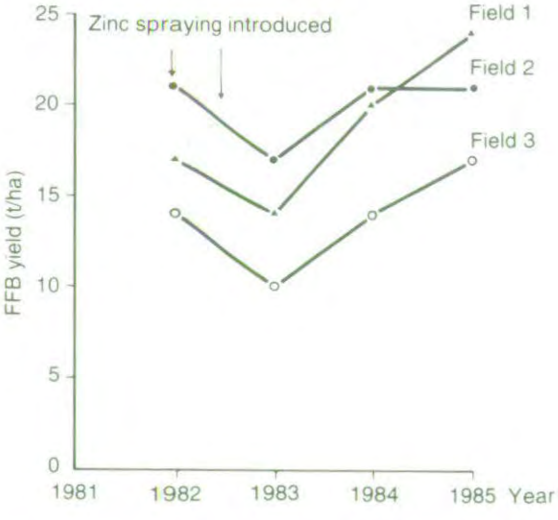

Fig 5. Progress in the rehabilitation of peat yellows by zinc sulphate spraying. Source: *Singh [1987]*

Application of zinc had a synergistic effect on the uptake of potassium and also improved the N, P and Cu status of treated palms. The author observed severe stunting of young oil palms due to the application of soluble phosphate (TSP) on a sandy muck soil in Sumatra. This stunting was most likely due to zinc deficiency induced by phosphate application.

For healthy growth Zn concentrations in leaves should be maintained between 12 and 18 ppm.

4.2.3.4. Iron (Fe)

Iron deficiency in the field is rare and usually limited to palms planted on or near former termite mounds or on outcrops of coral limestone. Fe deficiency is expressed as a whitish mottle of the youngest fronds of the canopy.

4.2.3.5. Manganese (Mn)

Manganese deficiency can occasionally be found on oil palms grown on deep peat, especially where heavy rates of limestone have been applied. Mn deficiency shows as a pronounced inter-veinal chlorosis of pinnae in the upper part of the canopy, giving them a distinct stripy appearance. The disorder is rarely serious enough to warrant treatment, but sprays with manganese sulphate (1-2%) should correct Mn deficiency. Mn deficiency is indicated by a Mn-concentration below 35 ppm.

4.2.3.6. Molybdenum (Mo)

Although most acid soils of the tropics are low in molybdenum, there are no known cases of a response of oil palm to applied Mo. Leguminous cover crops, however, may in some locations benefit from a one-time Mo application. The optimum Mo concentration in oil palm leaf tissue is 0.5 - 0.8 ppm.

4.3. Multiple nutrient deficiencies, excesses and imbalance

In the field there will always be cases when more than one element is deficient, while others are present in excessive amounts. In such cases the plants may exhibit a wide variety of symptoms that differ considerably from single nutrient deficiency symptoms. "White stripe" is probably the most widely encountered symptom caused by various imbalances, most of which are related to an excess of nitrogen and shortages of potassium and boron.

Plate 1 Excellent 32 month old oil palm, entering the first full year of harvest. Good planting material, rigid selection (culling) in the nursery, liberal fertilizer application and good upkeep can result in first year of harvest yields of 15 – 20 tonnes of FFB/ha. Note the size of the bunches and that all the lower fronds have been maintained.

Plate 2 *Nitrogen* deficiency is expressed by a general paling of the fronds. Nitrogen deficiency is usually associated with poor drainage, erosion of top-soil or infestation with grasses.

Plate 3 and 4 The most common symptom of *Potassium* deficiency is "confluent orange spotting", starting with small rectangular, pale green spots on pinnae of older fronds. These spots later turn orange and in severe cases the centre of the spots and the tips and margins of affected pinnae will become necrotic.

Plate 5 Oil palm pinnae suffering from magnesium deficiency develop a chlorosis that gives them a bright orange colour. A diagnostic feature of Mg deficiency is the absence of chlorosis in those parts of the tissue that have been protected from direct sunlight.

Plate 6 Oil palm leaves affected by boron deficiency can express a variety of different symptoms. Boron-deficient tissue is dark green, brittle and misshapen. This picture shows a combination of "hook leaf" and "blind leaf" symptoms. Boron deficiency is on the increase, especially since the introduction of the pollinating weevil *Elaeidobius kamerunicus*.

Some forms of "peat yellows" may not be a straight forward Zn- deficiency but may involve deficiencies of potassium and copper and an excess of magnesium.

4.4. Toxicities

Nickel (Ni) toxicity is probably the only significant soil-borne toxicity so far encountered. Nickel toxicity can be a problem on soils derived from ultrabasic "serpentine" rocks. Palms suffering from Ni-toxicity exhibit narrow, fish-net like chlorotic patterns on their younger leaves. Growth can be severely retarded. Soil borne Ni-toxicity is difficult to overcome. Mulching with empty bunches - where available - liming and extra potash (K) dressing can help to alleviate the problem.

Some sources of poor quality rock phosphate are known to contain high concentrations of nickel.

Cu and B toxicities may develop as a result of excessive application or as a result of using excessive amounts of Cu- containing fungicides.

4.5. Herbicide damage

Hand-weeding is increasingly replaced by herbicide spraying, particularly where labour shortages and costs are a problem. Herbicide damage may, in many instances, resemble nutrient deficiencies and symptoms caused by severe nutrient imbalances or by wind. Systemic herbicides are therefore not recommended for use in young immature stands of oil palm.

5. Nutrient interactions

No nutrient can act in isolation. Only where all nutrients are in complete "balance" or "harmony" with the physiological needs of the palm, can the full efficient use of each single component be achieved.

In theory nutrient interactions among all nutrients would have to be expected. In actual field practice, only interactions among the main nutrients (N, P and K) and Mg are of general interest. Interaction between N and P, N and K, K and Mg and K and B are most widely encountered, though many other interactions may be of significance under specific conditions (see Table 12 for example.)

Below are some examples:

On P-deficient soils, response to applied N and K are often absent, unless the P deficiency is corrected.

Table 13 shows a typical example of a positive N x P interaction.

Table 13. N x P interaction as observed in a fertilizer experiment in Indonesia

Treatments[a] $(NH_4)_2SO_4$ (g/tree/year)	Average contents in N (%) (F 17/1975-1979)				Average yield (kg FFB/tree/year) 1975-1976 to 1978-1979			
	P_0	P_1	P_2	X	P_0	P_1	P_2	X
N_0	2.11	2.11	2.15	2.12	89	108	127	108
N_2 4000	2.39	2.38	2.43	2.40*	126	158	187	158*
N_1 6000	2.37	2.48	2.47	2.44*	110	178	177	155*

[a] N_1 increased from 2000 to 6000 g/tree/year in 1974.

* Significant at $P<0.01$ level.

Source: *Ollagnier and Ochs [1981]*

With insufficient K increasing rates of N tend to depress the oil to bunch ratio and vice versa. With adequate N and K the opposite is true (Table 14).

Table 14. Interaction between the effect of N and K fertilizers and oil to bunch ratio

Trial No.	Year		Oil/bunch ratio (%) N_0	N_1	N_2	L.S.D.
81	1985	K_0	27.12	23.38	23.95	2.95
		K_1	25.01	24.77	24.19	
		K_2	23.45	24.55	25.37	
71	1986	K_0	26.92	25.59	24.84	3.01
		K_1	23.74	24.59	21.30	
		K_2	22.80	23.54	24.14	

Source: *Foster et al. [1988]*

Similarly K had no effect on yield and vegetative dry matter in the absence of applied N fertilizer, but significantly increased both yield and vegetative dry matter where N was applied (Table 15).

Table 15. Effect of N/K interaction on yield and vegetative dry matter in trial 57 (typic paleudult)

	N_0			N_1			N_2			Interaction effect	
Parameters	K_0	K_1	K_2	K_0	K_1	K_2	K_0	K_1	K_2	NK	s.e.
Yield (kg/palm/year)	71.6	65.3	66.3	68.4	95.2	95.8	79.1	95.8	98.6	12.4	± 4.34
VDM (kg/palm/year)	88.9	84.0	89.2	96.6	117.4	119.4	106.4	120.0	123.0	8.15	± 3.97

Source: *Chan [1981]*

Optimum rate of one fertilizer therefore always depend on the rates of other fertilizers applied. On the basis of long-term experiments on two different soil types (Ultisol and Oxisol) *Foong and Omar [1988]* calculated that for the Rengam series soil (Typic paleudult) the optimum combination was 0.83 kg N (or 3.2 kg of Nitro 26) and 2.22 kg K_2O/palm (3.7 kg KCl). On the Kuantan series (Haplic acrorthox) the combination N2 (2.3 kg of "Nitro 26") and K3 (3.99 kg KCl/palm per year) resulted in the highest yield (Table 16).

Table 16. Mean FFB yield (kg/palm/year) for all treatments over a 6-year period (1980-85)

	Fertilizer level	Yield (FFB/kg/palm/year) N_1	N_2	N_3	N_4
A. Renggam Series (Typic paleudult)	K_1	141.6	154.3	156.2	157.9
	K_2	140.4	159.6	159.1	158.2
	K_3	158.6	163.1	167.1	167.8
	K_4	143.9	168.3	174.2	163.9
	LSD (5%) = 15.1				
B. Kuantan Series (Haplic acrorthox)	K_1	160.2	178.4	183.1	179.8
	K_2	174.3	197.3	188.9	195.1
	K_3	199.8	206.5	195.2	200.1
	K_4	186.2	191.7	190.9	191.3
	LSD (5%) = 16.6				

Source: *Foong and Omar [1988]*

The interaction effect between N and Mg on frond lengths is shown in Table 17. In the absence of K, addition of Mg had a negative effect on yield, whereas in the presence of K significant yield increases were observed (Table 18).

Table 17. Effect of N and Mg on frond length (cm) measured in August 1958 (fourth year)

	Mg_0		Mg_1
N_0	381.0		362.8
N_1	384.0		389.0
		s.e. ± 3.04	

Source: *Chan [1981]*

Table 18. Effect of Mg on mean yield in low Mg plots between 1956 and 1959 in trial 18 on 24-year-old palms (ex-jungle soils)

Mg level	Mean yield, kg/palm/year (1956-1959) K_0	K_1	K_2
Mg_0	71.2	88.0	99.2
Mg_1	67.6	97.7	103.9

Source: *Chan and Rajaratnam [1977]*

6. Assessment of fertilizer needs

6.1. General remarks

Among major crops the oil palm has probably the highest percentage of crop area under intensive fertilizer treatment. Fertilizer also accounts for the lion's share in production costs. Because of the central role of fertilizer in palm oil production, considerable efforts have been made to develop methods providing a sound basis for estimating fertilizer needs.

Unfortunately such a "sound " basis does not exist and many plantation managers place excessive confidence in such "scientific" methods as soil and leaf analysis.

The final crop is the interaction product of so many different factors, some of which cannot be controlled or predicted, that exact prescriptions are just not possible. In many cases sound experience and good common sense can come out with far better recommendations than "prescriptions" based on leaf analysis data, worked out in a remote analytical laboratory.

Fertilizer has to be seen as just one, though important and costly - part of a large integrated management package. In actual plantation practice, individual nutrients or fertilizers should never be seen in isolation. Since the period between flower initiation and the production of ripe fruit is approximately 44 months, the effect of corrective measures in fertilizer application can be expected over a correspondingly extended period. It is worth remembering that the underlying cause of low leaf nutrient levels and observed deficiency symptoms may be careless and incorrect application rather than insufficient doses. Indeed attention to application technique (spreading, use of calibrated measures, etc) may often eliminate the need to increase application rates.

6.2. Soil analysis

Currently available methods of soil analysis are of no value for the day to day fertilizer management decision. The main reason is that it is impossible to obtain representative soil samples, because of the uneven distribution of fertilizer.

However, a good soil survey, that clearly maps out different soil types and that provides information as to different soil management units, combined with an initial soil analysis can be of immense importance and help for the later management of the estate.

Ideally, the soil should be classified according to the soil taxonomy system and/or the system used by local research institutes so that trial results and issued recommendations can be applied and interpreted correctly.

6.3. Leaf analysis

Producing leaves and fruit throughout the year at a rather regular rate, the oil palm offers itself better to leaf analysis than most other crop plants. With oil palms it is relatively easy for an experienced and well trained leaf sampling team to collect leaf tissue of a consistent physiological age.

In contrast to soil analysis it is not difficult to obtain reasonably representative samples. In the ideal case about 1.2 - 1.4 palms per ha should be sampled with composite samples provided from 30 to 40 palms. Datum points should be clearly marked in each block. Ideally, one in ten palms are selected. The first is selected at random, and subsequent points are selected in a zig-zag pattern alternatively every tenth palm within the row and every tenth row. If possible, leaf sampling should be done on a yearly basis witb the samples taken at tbe same time of year and from the same datum points. It is always worthwhile for the sampling team to record any deficiency symptoms observed on the datum points since this information may help the laboratory to interpret leaf analysis results.

The reference tissue for leaf analysis for adult palms is the center part of pinnae (without midrib) from frond No. 17, which is in the upper centre of the crown. For young palms (up to year 3) pinnae from frond No. 9 are collected.

Provided that a good laboratory is used, there should be no concern about the chemical accuracy of well prepared samples.

The problem comes with the interpretation of the data. "Optimum" or "critical" values for individual nutrients can vary over a considerable range, depending on such factors as age of palms, moisture regime, balance with other nutrients, type of planting material, spacing and inter-palm competition, etc. It is therefore advisable to refer to "optimal" ranges rather than to "critical" or "optimal" values. "Critical" values for leaf 17 (and leaf 9) as suggested by IRHO *(Ochs and Olivin [1977])* for standard leaf analysis samplings are shown in Table 19.

Suggested nutrient ranges associated with optimum nutrition, deficiency and excess are given in Table 20.

Table 19. Critical values of major and secondary nutrients in oil palm

Leaf No.	N	P	K	Ca	Mg	Cl*	S*
17	2.50	0.15	1.00	0.60	0.24	0.55	0.22
9	2.75	0.16	1.25	0.60	0.24		

* Levels not yet firmly established.

Table 20. Nutrient concentration of oil palm leaves associated with deficiency, optimum nutrition and excess

		Deficiency	Optimum	Excess
A. Young palms (below 6 years)	N	< 2.5	2.6 – 2.9	> 3.1
	P	< 0.15	0.16 – 0.19	> 0.25
	K	< 1.0	1.1 – 1.30	> 1.8
	Mg	< 0.20	0.30 – 0.45	> 0.7
	Ca	< 0.30	0.50 – 0.70	> 1.0
	S	< 0.20	0.25 – 0.40	> 0.6
	Cl	< 0.25	0.50 – 0.70	> 1.0
	B (ppm)	< 8	15 – 25	> 35
	Cu (ppm)	< 3	5 – 7	> 15
	Zn (ppm)	< 10	15 – 20	> 50
B. Old palms (over 6 years)	N	< 2.3	2.4 – 2.8	> 3.0
	P	< 0.14	0.15 – 0.18	> 0.25
	K	< 0.75	0.90 – 1.2	> 1.60
	Mg	< 0.20	0.25 – 0.40	> 0.70
	Ca	< 0.25	0.50 – 0.75	> 1.00
	S	< 0.20	0.25 – 0.35	> 0.60
	Cl	< 0.25	0.50 – 0.70	> 1.00
	B (ppm)	< 8	15 – 25	> 40
	Cu (ppm)	< 3	5 – 8	> 15
	Zn (ppm)	< 10	12 – 18	> 80

Leaf analysis can provide very good information about nutrient imbalances, but it is and always will be very difficult and even dangerous to calculate fertilizer rates with any satisfactory degree of accuracy on the basis of leaf analysis data only.

Under good management the oil palm is so responsive to fertilizer that it almost always pays to use rates that are close to the agronomic maximum which in turn will depend on the prevailing soil, climate and management conditions.

Green [1976] draws attention to the dangers of over-reliance on what are currently accepted "critical" levels.

Green cites an experiment in Johore (W. Malaysia) that has shown significant responses to all four elements (N, P, K and Mg) and so provides data which serve to highlight some of the difficulties of interpretation of leaf analysis data.

Rates of fertilizers applied in Experiment PF 54 are given in Table 21 and yield and foliar composition data are given in Table 22a and 22b.

On the basis of the IRHO standards only, data (no fertilizer) for the years 1960-1970 suggest that only potassium was marginally deficient. However, application of potassium alone would have depressed yield below those obtained without fertilizer. On the other hand, the application of a complete N P K Mg fertilizer, regardless of the foliar evidence, actually increased yield by about 5 tonnes/ha. Again in the second period, 1970-1973 the complete N P K Mg treatment raised yields from 17.57 to 26.54 tonnes FFB/ha.

Leaf samples (frond 17) taken from palms suffering from inter-palm competition for light may provide misleading figures. Frond 17 in such palms is often physiologically much older than frond 17 from a palm receiving full sunlight. Similarly, because of the faster growth rate, frond No. 17 in young palms may be only 5-6 months old, whereas frond No. 17 in old palms could be 8 to 10 months old.

Table 21. Experiment PF 54: rates of fertilizer application (kg/palm/year of commercial fertilizers)*

	1966-1969			1970-1973		
N (Nitro – 26**)	0	1.36	2.72	0	2.27	4.54
P (Christmas Island rock phosphate)	0	2.72	5.44	0	2.27	4.54
K (Potassium chloride)	0	0.91	1.81	0	2.27	5.44
Mg (Kieserite)	0	0.91	1.81	0	1.36	2.72

* Doses were prescribed in lb/palm and have been converted here to metric units.
** Ammonium sulphate in 1966/67.

Source: *Green [1976]*

Table 22 a. Experiment PF 54: Yield and foliar composition (calculated values) for some treatment combinations (mean 1966-1970)

		Yield	Elements as % of dry matter in leaf 17			
		(tons/ha)	N	P	K	Mg
No fertiliser		18.66	2.76	0.172	0.926	0.288
Single elements						
Nitrogen	1000	18.60	2.81	0.170	0.963	0.272
	2000	18.52	2.85*	0.173	0.916	0.285
Phosphorus	0100	21.89*	2.82	0.181*	0.973	0.256
	0200	22.90**	2.86*	0.185**	0.916	0.279
Potassium	0010	16.37	2.75	0.165	1.047*	0.276
	0020	17.97	2.71	0.165	1.119**	0.275
Magnesium	0001	21.03	2.76	0.174	0.865	0.309
	0002	18.68	2.68	0.166	0.819	0.348*
Pairs of elements						
N and P	1100	21.83*	2.87**	0.183**	0.883	0.261
	2200	20.83	2.96**	0.188**	0.849	0.288
N and K	1010	17.65	2.85*	0.165	1.147**	0.247
	2020	20.87	2.81	0.169	1.162**	0.225*
N and Mg	1001	20.36	2.78	0.168	0.959	0.297
	2002	18.17	2.82	0.168	0.838	0.368**
P and K	0110	20.42	2.73	0.174	1.090**	0.241*
	0220	22.84**	2.76	0.176	1.116**	0.258
P and Mg	0101	22.53*	2.79	0.181*	0.914	0.298
	0202	21.35	2.73	0.177	0.821	0.349**
K and Mg	0011	20.51	2.83	0.175	0.989	0.314
	0022	19.92	2.70	0.166	0.970	0.335*
Three elements						
N P K	1110	21.69*	2.84	0.178	1.064*	0.232*
	2220	23.80**	2.88**	0.182*	1.103**	0.221**
P K Mg	0111	22.82**	2.79	0.180*	1.014	0.299
	0222	23.22**	2.70	0.175	0.980	0.328
Four elements						
N P K Mg	1111	23.49**	2.87**	0.180*	1.046*	0.295*
	2222	23.80**	2.87**	0.182*	0.997	0.313
Sig. diff.	5% Level	2.993	0.081	0.0080	0.1083	0.0458
	1% Level	4.005	0.108	0.0107	0.1448	0.0613

Source: *Green [1976]*

Table 22 b. Experiment PF 54: Yield and foliar composition (calculated values) for some treatment combinations (yield: mean 1970-1973, foliar sampling in April 1972)

		Yield (tons/ha)	Elements as % of dry matter in leaf 17			
			N	P	K	Mg
No fertiliser		17.57	2.50	0.144	0.793	0.259
Single elements						
Nitrogen	1000	16.83	2.68	0.148	0.857	0.232
	2000	17.57	2.68	0.151	0.805	0.268
Phosphorus	0100	18.72	2.49	0.154*	0.821	0.246
	0200	20.67	2.47	0.157**	0.720	0.275
Potassium	0010	15.22	2.49	0.140	1.114**	0.238
	0020	15.78	2.34	0.139	1.262**	0.214
Magnesium	0001	19.25	2.44	0.145	0.664	0.330
	0002	16.14	2.28	0.137	0.644	0.424**
Pairs of elements						
N and P	1100	18.90	2.65	0.165**	0.646	0.250
	2200	18.91	2.68	0.171**	0.627*	0.313
N and K	1010	18.30	2.72	0.143	1.386**	0.155**
	2020	22.70*	2.64	0.151	1.448**	0.113**
N and Mg	1001	19.26	2.56	0.145	0.768	0.318
	2002	16.26	2.60	0.142	0.624*	0.481**
P and K	0110	17.96	2.46	0.146	1.133**	0.234
	0220	20.36	2.26*	0.148	1.223**	0.201
P and Mg	0101	20.24	2.39	0.151	0.743	0.319
	0202	18.20	2.28	0.148	0.623*	0.446**
K and Mg	0011	18.18	2.46	0.146	0.918	0.338*
	0022	17.71	2.28	0.140	0.983*	0.355*
Three elements						
N P K	1110	21.97*	2.68	0.157**	1.166**	0.182*
	2220	25.52**	2.60	0.168**	1.304**	0.129**
P K Mg	0111	20.77	2.39	0.149	0.988*	0.336*
	0222	21.25	2.23*	0.148	0.996*	0.349*
Four elements						
N P K Mg	1111	25.51**	2.55	0.156**	1.061**	0.301
	2222	26.54**	2.70	0.166**	1.046**	0.325
Sig. diff.	5% Level	4.141	0.232	0.0093	0.1609	0.0729
	1% Level	5.540	0.312	0.0125	0.2153	0.0975

Source: *Green [1976]*

The real benefits from an investment in leaf analysis are only felt when a series of results have been accumulated over a period of three to four years, since by this time, anomalies in individual years are outweighed by more meaningful long-term trends. It is then possible to review leaf analysis trends together with past production data and fertilizer applications, visual symptoms observed in the field and past soil analysis results to gain an informative over-view of future nutritional requirements.

6.4. Experiment and observation trials

Although fertilizer experiments continue to provide the most accurate information on fertilizer response, meaningful fertilizer experiments with oil palms are very complicated, expensive and time consuming and therefore beyond the scope of the commercial estate.

Valuable information can, however, be obtained by the introduction of "observation blocks" within the estate. In most cases the estate will keep accurate field or block yield records. The "standard" adopted estate practice includes a central block, and for each nutrient there will be one block with half and one with double the standard fertilizer rate.

Assuming the standard rate is 2 kg urea, 1.5 kg rock phosphate, 2.5 kg potassium chloride and 1 kg kieserite per palm per year, treatments for 9 observation blocks would be as shown in Table 23.

Table 23. Suggested fertilizer observation blocks for oil palm estates

	Urea	Reactive rock phosphate	KCI	Kieserite	Block No.
Standard*	2	1.5	2.5	1.0	1
Half N	1	1.5	2.5	1.0	2
Double N	4	1.5	2.5	1.0	3
Half P	2	0.75	2.5	1.0	4
Double P	2	3.0	2.5	1.0	5
Half K	2	1.5	1.25	1.0	6
Double K	2	1.5	5.0	1.0	7
Half Mg	2	1.5	2.5	0.5	8
Double Mg	2	1.5	2.5	2.0	9

* Estate pratice

If such blocks are maintained and yields are properly recorded, the results can, over a number of years provide most valuable information at minimum cost, especially now that most estates have a computer that can store and release data whenever available and needed. The results can also be useful for the interpretation of leaf analysis data and for the formulation and fine tuning of fertilizer treatments.

In order to effectively monitor yield trends, it is essential to keep 12 month rolling yield (tonnes/ha) records. Such records presented graphically give a very clear indication of yield trends over the production cycle.

7. Non fertilizer factors influencing fertilizer responses

7.1. General

It can be assumed that the yield potential of properly selected, and carefully planted palms is 50 tonnes FFB/ha during the peak years of production (year 6 – 9 from planting) providing that there are no stress factors (climate, soil and management) present.

There are only a few areas in the world with no or only minimal climatic and soil constraints. Certain areas in West Sumatra provide an almost optimum environment with free draining volcanic soils, evenly distributed high rainfall and good solar radiation. However, even under such optimal conditions of soil and climate, actual yields rarely exceed 34 tonnes of FFB/ha or 68% of the theoretical or assumed yield potential. To maximize yields and to optimize return from all inputs it is important to know all constraints and to eliminate those that can be modified or manipulated.

Experience suggests that a key factor in the implementation of sound practices is the compilation of a set of simple, coherent management policy papers giving site specific (e.g. soil, climate, planting material) recommendations for the objective, standard, procedure and frequency of each task. Furthermore, supervisory staff engaged in the implementation of field policy should be properly trained so that there is a clear understanding between management and staff of the standards required and the methods to be used.

7.2. Nursery selection

As long as the planting material consists of DxP or DxT crosses, there will be considerable heterogenity among individual plants. Since some crosses (seed batches) produce as many as 25-30% off- types or runts, the separation of identified crosses in the nursery will pay dividends to the planter who is then able to select seedlings with a "type", and possibly modify his future seed orders to exclude crosses which have not performed well in the nursery.

In many estates it is common to find 10 to 15 runts, off-types and low yielding palms per hectare in the stand. Such palms will never respond to fertilizer and at the same time 10% runts and off-types in the stand will bring down the yield potential by at least 10% because of the tendency of low yielding/sterile palms to grow faster than neighbouring productive palms thereby depriving them of light. It is quite a safe assumption that with current practices 10% of the yield potential is lost because of insufficient care in nursery selection borne out of insufficient understanding of the principles involved. Mistakes in nursery selection are very difficult and expensive to correct at a later stage. Furthermore, heterogenity in the final stand makes it difficult for the estate to formulate a management policy (pruning, fertilizer programme, etc) which can be applied uniformly throughout the plantation.

Assuming again a maximum yield potential of 50 tonnes FFB/ha , the common mistakes found in the nursery will reduce the potential yield to a maximum of 45 tonnes FFB/ha.

7.3. Land clearing and preparation

Since oil palm developments are a long term investment continuing in some cases for over fifty years, short-sightedness during the early establishment phase of two years affects the production costs and returns over a considerable period of time. Therefore, it is never advisable to cut costs and compromise the high standards required during the establishment phase if the planter is to realise the long term returns from his estate. The potential response to fertilizer can never be realised where irreparable damage has been done to the soil through "cheaper" land clearing methods.

The key to fertility in tropical soils lies in the thin layer of soil , rich in organic matter, lying at the surface. Land clearing techniques should always aim to conserve this fragile layer if optimal returns are to be expected from fertilizers applied in later years. Expenditure on careful land clearing and the establishment of a vigorous cover crop in the first year will pay enormous dividends and result in large savings in upkeep and fertilizer costs throughout the productive life of the palms.

A considerable body of research work now available points to the importance of a number of key factors in land clearing and soil management.

The mechanical clearing of rain forest has been shown to cause serious structural damage to the soil which may be impossible or at best expensive to correct. Where sufficient labour is available, manual clearing is often a cheaper alternative and certainly results in higher residual fertility and minimal structural damage. Where labour is in short supply, care in the selection and use of machinery for land clearing deserves close attention.

Since soil organic matter has been identified as a key factor in the retention of nutrients in an available form, the burning of felled vegetation to ease the establishment of covers immediately compromises the future efficiency of fertilizer use. On some soils, burning adversely affects subsequent soil water relations.

Drainage problems should always be attended to prior to the planting of cover crop and palms if both plants are to respond to residual and applied soil nutrients.

Caliman and de Kochko [1987] pointed out a number of techniques which can be used on sloping land to reduce soil water run-off and erosion. Clearing and windowing should be carried out according to topography. Windrows created in this way provide effective water run-off dams whilst cover crops tend to develop more rapidly along these lines forming anti-erosion plant belts along the contour.

On gentle slopes, cover crops and the arrangement of cut fronds along the contour line may suffice. On steeper land, contour planting, the construction of platforms or terraces, and bunds along the contour line are deemed essential to minimize soil loss and run-off. Where appropriate techniques are deployed, residual fertility is enhanced and with the retention of surface organic matter, a better response to fertilizer can be expected.

The potential yield of the stand is therefore always reduced through careless and inappropriate land preparation techniques.

7.4. Ground covers and ground cover management

All experienced planters will realize the importance of a good cover regime. Dominance of noxious weeds like *Mikania cordata, Imperata cylindrica* and *Asytasia coromandeliana* can reduce yields by up to 20%. Dominance of grasses such as *Imperata cylindrica* and difficulties in the establishment of a vigorous leguminous cover crop is usually an indication that the soil is extremely deficient in P. In such cases it is advisable to broadcast 500 kg/ha of a reactive rock phosphate after the eradication of the grass vegetation and before planting the cover crop.

In an experiment with rubber, *Pushparajah and co-workers [1969]* demonstrated a better response to phosphate when rock phosphate was applied to legume covers (thus cycling it to trees through the leaf litter) than directly to the trees. Similar beneficial effects have been observed where Mg, and K fertilizers have been applied in the inter-row.

After two years under a well established and properly fertilized cover crop, degraded soils will be substantially rejuvinated and well managed oil palm developments established on marginal savannah soils appear, from the air, as oases of soil rehabilitation.

A well established leguminous cover crop can fix more than 300 kg of N per hectare (Table 24) thereby greatly reducing the need for chemical nitrogen fertilizer.

Table 24. Dry matter, litter production and N immobilization by leguminous covers, grasses and *Mikania*

	Selangor Series soil[1]				Serdang series soil[2]			
	kg/ha				kg/ha			
Cover	Dry matter	Litter	Total	N	Dry matter	Litter	Total	N
Pueraria phaseoloides	4950	5147	10097	227	5823	4829	10652	289
Calopogonium caeruleum	8382	7145	15527	292	5924	3005	8929	191
Calopogonium pubescens	5383	7901	13284	386	4487	6711	11198	294
Desmodium ovalifolium	15191	4287	19478	232	11436	3953	15389	214
Grasses	8359	6739	15098	109	5492	4945	10437	90
Mikania micrantha	–	–	–	–	4333	1653	5986	75

1 At 20 months after planting.
2 At 12 months after planting.

Source: adapted from *Han and Chew [1982]*

As shown in Table 25 yields are much higher in plots having a leguminous cover than in plots having a non-leguminous *(Mikania)* cover. There was no response to applied N under leguminous cover but a 16% yield response to N was found where the ground cover consisted of *Mikania.*

However, the main benefit from a vigorous thick cover crop is its ability to provide a canopy over the soil thereby protecting the soil surface, keeping the soil surface cool and moist, preventing or reducing soil erosion, from the rapid cycling of nutrients and organic matter, and providing an environment conducive to beneficial insects involved in the biological control of pests.

It is important to include species in the cover seed mixture which will still prevail once the canopy closes, such as *Calopogonium caerulium. Yeow et al [1982]* showed that the residual effect of planting cover crops persisted for at least ten years after establishment.

Any vigorous ground vegetation can at times compete with the oil palms for nutrients and water and there is experimental evidence to show that in the short run growth and yield can be better under bare soil *(Chew and Khoo [1977])* but in the long run a "good" soil cover will always give better returns by preventing surface erosion damage to our primary resource base - the soil.

Table 25. Yield from different cover crop treatments on Selangor Series clay (entisol, tonnes FFB/ha)

Treatment		Years					Total	% of *Pueraria* + fertilizer
		2.5-3.5	3.5-4.5	4.5-5.5	5.5-6.5	6.5-7.5		
Grass	NF	10.50	20.83	26.76	27.16	25.75	111.00	92.5%
	F	11.12	21.15	25.70	26.86	26.02	110.85	92.4%
Mikania	NF	5.76	18.51	22.86	23.01	24.04	94.17	78.5%
	F	7.46	19.77	25.38	26.71	27.23	106.55	88.8%
Nephrolepis	NF	8.67	19.15	25.87	25.11	24.51	103.31	86.1%
	F	9.96	21.60	28.64	28.27	28.29	116.75	97.3%
Pueraria + Centrosema	NF	11.71	24.56	26.71	27.53	27.33	117.84	98.2%
	F	12.08	24.27	27.35	28.37	27.90	119.97	100.0%
Flemingia	NF	10.82	23.01	25.30	26.24	25.65	111.02	92.5%
	F	11.44	24.12	25.50	27.60	25.87	114.53	95.5%
Flemingia + Pueraria + Centrosema	NF	11.93	23.47	25.28	25.75	26.12	112.55	93.8%
	F	11.24	22.54	26.04	28.05	28.66	116.53	97.1%

F = fertilizer added.
NF = no fertilizer.

Source: Adapted from *Gray and Hew [1968]*

7.5. Vigour of seedlings, transplanting age and quality of field plantings

In order to realize the potential benefits which accrue from the preparation of high quality seedlings, careful land preparation and good cover establishment, extreme care and attention is required during the very short period of field planting. Even some very experienced planters under estimate the importance of having uniformly vigorous seedlings of optimum age (11-15 months), planted into well prepared planting holes at the right depth (the base of the bole level with the soil surface).

It is frequently observed that the potential benefits from care and attention given during the 12 month nursery period to produce high quality seedlings are lost by carelessness during the ten minutes involved in palm planting. Quality seedlings planted at the optimum stage during favourable climatic conditions will suffer negligible transplanting shock. Conversely, recklessly planted palms will be disadvantaged in receiving solar energy due to the dessication of the lower traumatized leaves, and therefore may never fully develop their yield potential. It is safe to assume that up to 5% of the yield potential is lost due to mistakes in the nursery (other than selection and culling) and field planting. Thus the yield potential is reduced by a further 2.25 tonnes to 42.75 tonnes FFB/ha.

7.6. Circle weeding and care of young immature palms

During the first 3 to 4 years in the field there is no inter-palm competition. For this reason it is of the utmost importance that all green fronds are retained and that pruning is limited to the removal of dried up non-productive fronds. If a vigorous stand of covers has been established, inter-row weeding will be relatively easy and inexpensive during this period, with the only requirement that cover crop runners are regularly pulled out of the palm circle on a three weekly basis. Chemical circle weeding should be avoided in young palms as this often tends to cause damage to older fronds.
Ablation should be avoided in young palms as this often tends to cause damage to older fronds. Ablation should only be practised where both soil and climate are limiting. Where there is no moisture deficit, and where soils are fertile, ablation is not advisable as it may result in a very high sex ratio and resultant shortage of pollen in the first two years of production. This in turn causes a high proportion of parthenocarpic fruit, abortion and bunch rot in young palms.

During this stage, abnormal and unproductive palms which were not culled in the nursery should be marked , removed, and replanted with supplies before the palm canopy starts to close.

On severely degraded drought prone soils, an application of 20 - 30 empty bunches at this stage in a circle one metre distant from the base of the palm will help considerably in the development of early yield.

7.7. Optimum leaf area index

Few crops are as sensitive to light competition as the oil and coconut palms.

The selection of the most appropriate planting density is a complex matter and is given full coverage by *Corley [1976]*. It is worth mentioning here that there is a compromise between the need to establish optimum LAI as early as possible (favoured by high density) and the requirement to minimize inter-palm competition once the canopy has closed (favoured by lower initial planting densities).

Young palms, where inter-palm competition for light is not a problem tend to respond to fertilizer (N and K in particular) on nearly all soils. Indeed correct nitrogen nutrition plays a key role in promoting fast canopy closure and the early establishment of an optimal LAI.

With older palms (6-8 years or older) inter-palm competition often becomes a problem, especially where there are few limitations from fertility and moisture supply (e.g. marine or river alluvium and young volcanic soils in high rainfall areas). Fertilizer applications to palms suffering from inter-palm competition for light (excessive LAI) may decrease rather than increase yields of FFB by accentuating the inter-palm competition. In such cases, thinning is strongly recommended (see Table 26). In most cases it is advisable to start by first marking all runts and unproductive palms. After a period of 12-36 months of monitoring, palms which are still unproductive should be removed. Later systematic thinning should be considered where one palm in seven is poisoned out.

Table 26. Effects of thinning mature oil palms in Sabah (t/ha)

	Planting			
Year	1964[a] (170 ha)	1965[a] (220 ha)	1966[b] (170 ha)	1967 (112 ha)
9	22.7	22.5	21.8	18.3
10	19.9	19.4	18.4	13.9[+]
11	16.6	18.9[+]	14.8[+]	18.8
12	16.6+	19.0	17.4	18.5
13	15.2	22.1	19.1	21.0
14	19.6	21.4	19.6	23.8
15	19.0	22.6	17.7	26.0
16	23.6	21.3	20.0	19.9
17	23.3	22.6	18.6	23.2
18	28.1	21.0	21.9	
19	25.8	21.0		
20	27.5	19.3		
21	25.2	22.2		
22 (1986)	22.3			

[a] Alluvial soils.
[b] Sedentary soils.
[+] Thinning.

Source: *Ooi et al. [1989]*

7.8. Pruning

From planting to year six, it is important to retain the maximum number of productive fronds for rapid growth, optimal response to applied fertilizer, and high early yield. All productive leaves should be retained and damage to older green leaves through circle weeding or herbicide use should be avoided as far as possible. The aim with young palms should be to retain 7 to 8 full spirals (56-64 leaves).

In mature palms, the optimum leaf number ranges from 4. 5 to 6 spirals (36-48 leaves), depending on spacing, frond length of individual palms (planting material) and climatic stress (Table 27).

Table 27. Optimum leaf number by age

Age of palms in field*		2	3	4	5	6	7	8	10	16
Optimum leaf no.	a.	64	56	54	51	48	46	44	40	38
	b.	64	56	52	48	45	42	40	38	36
	c.	64	56	50	46	43	40	40	38	36

* End of year
a. Spacing: 126/ha
b. Spacing: 138/ha
c. Spacing: 143/ha

To maintain an excessive number of fronds in mature palms can be just as detrimental to yields as the over pruning of young palms .

Wood (1976) reports that in mature plantations, the cut fronds have a dry weight in excess of 10 tonnes dry matter/ha with a nutrient value equivalent to 58 kg urea/ha, 30 kg/ha rock phosphate, 120 kg/ha KC1, and 70 kg/ha kieserite. Cut fronds should therefore be carefully spread over the inter-row to ensure an even spread of these recycled nutrients.

7.9. Erosion control and water conservation

Surface erosion and leaching can be very serious problems in the high rainfall areas of the tropics where oil palms are grown. Loss of parts of the top soil can mean the loss of most of the plant available soil P and Mg and can greatly reduce plant available water. The overall effect is increased stress for the palms and decreased bunch production.

In erosion prone areas, mulching with empty bunches is strongly advocated (Table 28).

Table 28. Effects of mulching oil palm on yield*

	FFB (t/ha/year)	Bunch No.	Bunch weight (kg)
Mulched	31.9	8.92	25.0
Not mulched	28.7	8.29	23.8

* After *Chan K.W. et al. [1985]*

7.10. Pest and disease control

Fortunately pest and disease problems are so far not very serious in the main oil palm growing areas of the world (S.E. Asia), though at times losses can be very high in limited areas. Main losses are due to leaf-eating pests such as nettle caterpillars, hagworms and grasshoppers. Occasionally *Oryctes rhinocerous* beetles can be a problem where good breeding grounds (rotting wood) exist. The author has repeatedly observed increased nettle caterpillar damage in palms over-fertilized with nitrogen and increased grasshopper damage to young palms that had not received KCl.

Porcupines, rats and wild pigs can be major pests in young palms, and occasionally even elephants. Rat control in mature palms can be very important but one should be careful in the selection of rat poisons so as to do mimimal damage to their natural predators.

Among diseases basal stem rot, caused by a number of species of *Ganoderma* is the only pathogenic disease of real significance in S.E. Asia. In Africa and Latin America the oil palm is threatened by a number of diseases, some of which are of unknown etiology. Diseases and disorders in oil palms are comprehensively covered by *Turner [1981[.*

Where an efficient early warning system is used, pest and disease outbreaks can be controlled before severe economic damage is experienced. Considerable advances in the field of biological pest control have been made in recent years including the use of barn owls for rat control and viral pathogens on leaf eating caterpillars. For this reason, inter row management should always aim to create an environment which encourages natural predators of pests.

7.11. Harvesting and fruit collection

In many cases larges quantities of fruit or oil is lost due to too late or too early harvesting and due to incomplete collection of loose fruit. Good field sanitation, layout and maintenance of roads and harvesting path are an essential component for inspection, supervision and harvesting and the overall performance of the plantation and thus also a factor for improved fertilizer use efficiency.

8. Fertilizing for maximum return

8.1. General

On most plantations fertilizer is the highest cost item in oil palm cultivation. The importance of using appropriate management techniques to optimize the efficiency of fertilizer utilization has already been discussed in previous chapters.

"Improved oil palm nutrition has probably been the single most important factor in the advancement of oil palm yields in Malaysia in the last decade" *(Chew [1985]).* In order to draw up an appropriate fertilizer programme, the potential needs of the crop at the projected yield level must be known, and suitable fertilizer doses applied in such a way so as to minimize losses and maximize utilization by the crop.

8.2. Nutrient losses

Nutrient losses can occur through:

- inappropriate land clearing and preparation
- run-off and topsoil erosion
- leaching
- volatilization
- fixation

8.2.1. Land clearing and preparation

The importance of proper land clearing techniques in the preservation of residual fertility have been mentioned in the previous chapter. The replacement of lost soil fertility will invariably be more expensive and difficult than the cost of prudent land clearing and preparation techniques. Run-off, topsoil erosion, leaching, volatilization and fixation are all adversely affected by mechanical clearing, burning, the erosion of subsequently exposed soil, and the failure to establish covers.

8.2.2. Run-off and top soil erosion

This is the most serious path-way of fertility loss as it affects all nutrients.

P is not mobile in the soil, being held mainly in the uppermost few centimetres of top soil rich in organic matter. Therefore P supply is particularly badly affected by sheet erosion. Since covers, which protect the soil from erosion, are very difficult to establish on P deficient soils (through sheet erosion), the effect of top soil loss during land clearing exacerbates the supply of other nutrients by further exposing the soil to erosion.

Topsoil erosion exposes the most active feeder roots close to the surface and also reduces the water holding capacity of the soils and renders nutrients, especially magnesium, less available.

Losses through surface run-off and erosion can be reduced by:

- maintenance of a good ground cover

- contour planting and proper size and slope of terraces and platforms.

- spreading of cut fronds along the countour lines.

- mulching with empty bunches.

- avoiding fertilizer application during periods with heavy rainfall.

- preparation of contour soil bunds.

8.2.3. Leaching

Nitrogen (N), magnesium (Mg) and potassium (K) are the main nutrients that can be lost through leaching. Phosphorus (P) is rather immobile in the soil and P losses due to leaching are insignificant. Leaching losses can be high on light textured (sandy) soils, especially where the organic matter content is low and in areas with high rainfall. N and Mg are more mobile than K and can therefore be more easily lost.

Leaching losses can be greatly reduced by:

- splitting the fertilizer applications

- even spreading of the fertilizer over the entire rooted area (to maximize root interception and to maximize absorption of cations by the exchange complex).

- avoiding fertilizer application during periods of heavy rainfall

- application of organic matter (mulching with empty bunches).

- raising soil pH through liming in order to increase soil cation exchange capacity (CEC).

8.2.4. Volatilization

The only nutrient involved in volatilization losses is nitrogen (N), especially if urea is applied on a soil where moisture (from the soil or the air) is just enough to dissolve the urea and insufficient to wash the urea or its decomposition product (ammonium bicarbonate) into the soil. Under adverse conditions more than 70% of the applied N can be lost within one week.

N volatilization losses can be reduced by:

- applying N (urea) only during months when rainfall is assured
- covering applied N with soil (raking in)
- split application

8.2.5. Fixation

While N is the only nutrient involved in volatilization loss, losses due to fixation involve mainly phosphate (P). Fixation losses are not "losses" in the true sense like those due to run-off, leaching and volatilization. Fixation means only that the nutrient is being transformed from a readily available form into an unavailable or only very slowly available form.

Serious P fixation is mainly limited to water soluble forms of P (Triple-Super-Phosphate - TSP, Di Ammonium Phosphate - DAP and water soluble P in high quality NPK compounds) applied on acid soils, high in available iron and aluminium.

P fixation losses can be minimized by:

- minimizing soil contact of water soluble P-fertilizer (apply P in bands, over frond heaps, or the outer rim of the weeded circle)
- application of organic matter (mulching with empty bunches)
- establishment of vigorous cover crops to promote P-cycling
- application of lime

8.3. Fertilizer for oil palms

8.3.1. General

Oil palms are the most heavily fertilized tree crop grown in the tropics. Worldwide hundreds of millions of dollars can be gained by correct use of fertilizer. Similarly, millions of dollars of potential income are not realised by not applying enough or not applying the right fertilizer, or applying the right fertilizer wrongly.

During the economic lifetime of the oil palm there are four distinctly different phases each having rather specific requirements. These phases are:

1. Nursery phase (period from planting the germinated seed until the seedlings are planted in the field (10 - 18 months)).

2. Young immature phase (from field planting till the end of year 3 when harvesting commences).

3. Young mature phase (from the end of year 3 to year 9 or 10 from field planting).

4. Mature phase (from year 9 or 10 to re-planting).

8.3.2. Phase I The nursery

Fertilizer requirements during the nursery phase differ in many ways from the fertilizer requirements in the field.

Fertilizers are needed to produce healthy, vigorous seedlings which can overcome transplanting shock (when palms are more susceptible to leaf diseases) with a minimum set-back in growth.

It has become standard practice to use quality granular NPK Mg fertilizers that include trace elements to provide the seedlings with all essential nutrients. As the young seedlings are tender and have a limited root system, fertilizers are applied on a fortnightly basis during the first 48 weeks and on a 3 week basis thereafter. Where sub-soil or poor top soil is used to fill the polybag, extra dressings of magnesium at a rate of 10 to 15 g of kieserite may be required every 6 to 8 weeks.

Compacted slow release fertilizers have recently gained popularity. Excellent results have been obtained by applying one 7-8 g tablet of a 10-10-5-2 (N P K-Mg) fertilizer three weeks after planting into the small polybag in the pre-nursery and by applying 2-3 15-20 g tablets into the large polybag, about one month after transferring the properly selected seedling from the pre-nursery into the main nursery. Such slow release fertilizer usually provides adequate nutrition for up to 10 months.

Where high quality compound fertilizer or slow release fertilizer is not available, supplementary foliar fertilizer may be required, particularly if poor soil has been used in the polybags. All fertilizer application should be stopped one month prior to field planting.

In order to minimize nutrient losses (volatilization) and damage to young seedlings from fertilizer contained in irrigation "splash back", seedlings should be mulched with kernel shell or some other suitable material.

In dry areas, transplanting shock occurring when pre-nursery seedlings are transferred to the main nursery can be minimized if seedlings are shaded with nipa palm fronds arched over the newly planted seedling.

An example of a nursery fertilizer programme is given in Tables 29a and 29b.

Table 29 a. Pre-nursery program

Age of seedlings (weeks)	Fertilizer type and rate
4 (1st leaf)	30 g Urea in 18 l water per 400 seedlings
5	60 g 15/15/6/4 in 18 l water per 400 seedlings
6	60 g 15/15/6/4 in 18 l water per 400 seedlings
7	75 g 15/15/6/4 in 18 l water per 400 seedlings
8	90 g 15/15/6/4 in 18 l water per 400 seedlings

8.3.3. Phase II Young immature palms (Year 0-3)

Fertilizer requirements during the first 6 months after field planting are low because growth comes close to a temporary stand-still due to transplanting shock and because it takes some time for the seedlings to establish an effective root system. However, 250 to

Table 29 b. Main nursery program

Age of seedlings (weeks)	Fertilizer quantity per seedling
9	3.5 g 15/15/6/4
10	3.5 g 15/15/6/4
12	7 g 15/15/6/4
14	7 g 12/12/17/2 + TE
16	7 g 15/15/6/4
18	7 g 12/12/17/2 + TE + 7 g Kieserite
20	7 g 15/15/6/4
22	7 g 12/12/17/2 + TE
24*	7 g 15/15/6/4 + 7 g Kieserite
26	15 g 12/12/17/2 + TE
28	15 g 15/15/6/4
30	15 g 12/12/17/2 + TE
32	15 g 15/15/6/4 + 15 g Kieserite
34	30 g 12/12/17/2 + TE
36	30 g 12/12/17/2 + TE
38	30 g Kieserite
40	30 g 12/12/17/2 + TE
42	30 g Kieserite
44	30 g 12/12/17/2 + TE
46	30 g 12/12/17/2 + TE
48	30 g 12/12/17/2 + TE
51	30 g Kieserite
54	30 g 12/12/17/2 + TE
57	30 g 12/12/17/2 + TE
60	30 g 12/12/17/2 + TE + 30 g Kieserite

* Supplementary application of 15 - 30 g of Nitro 26 may be required at this stage of palm growth depending on appearance of the seedlings.

500 g of reactive rock phosphate should always be mixed with the soil used to fill around the newly planted seedling.

Once this initial phase is overcome, growth rates and fertilizer needs tend to expand at a very fast rate. In fact, the period from the start of year 2 to year 4 is a phase when palms respond most to applied fertilizer and when omission of regular fertilizer rounds can result in the largest set-back. Year two in the field is when frond production reaches its maximum (up to 48 fronds per year) and when the foundation for the first crop is laid down. While the growth rate is very fast, the root system is not yet fully developed and energy is required for frond, trunk and root development and for the development and formation of flowers that will eventually develop into the first harvestable crop.

Many planters tend to increase fertilizer rates only when the palms come into production in year three to four, thereby often loosing one full year of production. In optimal environments, where very high early yields are produced based on high solar radiation and rainfall, and good residual soil fertility, insufficient fertilizer application in the second and third year after planting can result in premature yield peaks. Thereafter, the palms will go through extended and recurring resting periods following the stress from massive early yields.

Table 30. Fertilizer schedule for young, immature palms

		Fertilizer (g/palm)					
Years	Month	Urea*	TSP/Rock phosphate**	KCl	Kieserite	Borate	Total
1***	0 (planting hole)	–	500	–	–	–	500
	1	50	–	–	–	–	50
	3	80	–	–	100	–	180
	6	100	–	100	–	–	200
	9	150	250	150	–	30	580
	12	180	–	200	–	–	380
Total year 1		560	750	450	100	30	1890
2	15	250	–	–	250	–	500
	18	250	500	500	–	60	1320
	21	400	–	750	250	–	1400
	24	600	500	1000	–	60	2100
Total year 2		1500	1000	2250	500	60	3310
3	27	750	–	1000	500	–	2250
	31	750	1500	1000	–	90	3340
	36	1000	–	1000	500	–	2500
Total year 3		2500	1500	3000	1000	90	8090

* Increase urea rates by 20% if there are no or few legumes in the ground cover.

** For young, immature palms TSP or DAP should be used. If rock phosphate is to be used, it should be highly reactive rock like NCRP.

*** Where labour is expensive and in short supply, slow release fertilizer tablets can be used. A one time application of 15-18 15-20 g tablets of an NPKMg slow-release fertilizer can last for a period of up to 10 months.

It is the time between 10 to 36 months from planting palms close attention and care is most needed. This includes careful circle weeding with minimum damage to lower fronds, ablation[1] (removal of inflorescences where oil palms are grown on poor soils or in areas affected by drought), and adequate and properly applied fertilizer. As the root system is not yet fully developed, all fertilizer should be applied within a distance from the trunk that does not exceed the length of the fronds in the middle of the crown.

During the first 36 months it is also advisable to use phosphate in water soluble form (TSP, DAP or quality N P K's) or in the form of highly reactive rock phosphate (such as North Carolina natural phosphate). An example of fertilizer schedules for the first 36 months is given in Table 30.

8.3.4. Phase III Young mature palms (4 to 9 years from planting)

This is the most productive period for most plantations. Palms which have been properly treated in the nursery, correctly planted at the right depth and age, and properly fertilized can easily produce a yield of 15 to 20 tonnes of FFB/ha in the first full year of harvest[2]. In many cases actual yields obtained in the first year do not exceed 5 tonnes of FFB/ha. Apart from inadequate early fertilizer, another reason for poor first and second year yield is the removal of green healthy and productive fronds during regular weeding rounds during the first 36 months before harvest begins.

Since there is no inter-palm competition for light during this period, every green frond should be retained. It is also important to remember that production from young palms comes from the bunch number and not from bunch weight. In many cases there may be a bunch in every frond axil. Due to ignorance or poor supervision young heavily bearing palms are often heavily over pruned, because more than one frond is often removed with every bunch harvested. Under such practice, the most heavily productive palms are stressed most and they may be forced into a male phase or a period of total rest due to the exhaustion of available carbohydrates and plant nutrients.

In young palms one should try to maintain at least two subtending fronds under each bunch. This means that one should try to harvest as many bunches as possible without

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[1] Ablation is not advisable where oil palms are grown in an optimum environment (good soil and no moisture deficit) as ablation under such conditions may cause a shortage of male flowers and pollen, causing bunch rot and parthenocarpic fruit.

[2] 22 bunches of 5 to 6.5 kg/bunch average bunch weight at 138 palms/ha = 15.18 to 19.74 tonnes FFB/ha.

cutting the subtending frond. In many cases harvesting tools may have to be changed - such as providing harvesters with narrow-bladed chisels.

During the young mature period, leaf production decreases from about 36 per year (3 per month) to 24 per year (2 per month) while frond length is still increasing.

To optimize fertilizer efficiency, a correct balance between applied fertilizer and the effective leaf area must be maintained.

6-7 spirals of fronds per palm (48-56 fronds per palm) are required in 4 to 6 year old palms. The optimum frond number will of course depend on the original planting density and the average frond length. In palms older than seven years, inter-palm competition may become a problem. Frond number should be reduced to 5 to 5.5 spirals (40-44 fronds per palm) and sterile or unproductive palms should be removed. This initially involves the marking of runts and off-types so that monitoring can continue for a period of two years until it is quite certain that marked palms are truly unproductive and not merely resting.

Table 31. Fertilizer schedule for young, mature palms

Year	Months after planting	Fertilizer, g/palm					
		Urea	TSP/Rock phosphate	KCl	Kieserite	Borate	Total
4	40	1000	1500	1500	500	100	4600
	46	1000	–	1500	500	–	3000
Total year 4		2000	1500	3000	1000	100	7600
5	52	2000	1500	2000	500	80	5080
	58	750	–	2000	500	–	3250
Total year 5		2750*	1500	4000	1000	80	8330
6-8	Twice per year	1000	1500**	2000	500	–***	5000
		1500	–	2000	500	–	4000

* Between year 4 and 5 it is advisable to cut back N (urea or ammonium sulphate) application where a good leguminous cover crop had persisted during the immature phase.

** P as rock phosphate.

*** Borate application may have to be continued through year 8 in some instances.

With most of the ground vegetation being shaded out, and the root system extending far beyond the area covered by the crown, fertilizer can be applied wherever there is the best chance of maximum root interception. Phosphate, potash and magnesium can be broadcast over the inter-row (e.g. by mechanical spreader once palms are tall enough to allow a tractor to pass). In this way, the retention of shade tolerant covers *(Calopogonium caerulium)* is encouraged which in turn improves the efficiency of fertilizer utilization. Phosphate utilization is usually best when spread over the cut frond heaps. Nitrogen should still preferably be spread over the weeded circle.

As the palms get older, there is no need to use expensive water soluble P sources. The use of quality rock phosphate is recommended for the maintenance of adequate P levels in mature palms.

An example of a fertilizer schedule for young mature palms is given in Table 31.

8.3.5. Phase IV Mature palms over 8 years

In most plantations yields peak from year 5 to year 8 and then start to decline. Leaf production stabilizes at about 18 to 24 per year, and yield comes increasingly from high bunch weight as bunch number declines. For this reason response to fertilizer is much slower than it is with young palms, where this year's fertilizer may already show some effect in the same year.

In young palms, husbandry techniques should aim to build up a sufficiently large leaf area (LAI = Leaf Area Index) by a combination of adequate fertilizer and minimum pruning. The approach to leaf area index and pruning has to be reversed after year 7 or 8. At this age an excessive leaf area rather than too small a leaf area is the problem. Shaded fronds may consume more energy than they produce. 36 to 40 fronds per palm is about the optimum frond number per palm.

Fertilizer response is in many cases dependent on proper thinning. Thinning has to start with the removal of runts and/or unproductive palms. The more favourable the environment (soil and climate) the more important thinning is in order to maintain a good response to fertilizer, and a high yield.

In most cases it is advisable to remove every 7th palm in a hexagonal/triangular arrangement, since the removal of one palm will benefit six surrounding palms. Such thinning will reduce the stand from an original planting density of 143 to 122 or from 138 to 118.

In mature palms no more benefit can be expected from applying fertilizer into the weeded circle. On the contrary, most experimental evidence suggests that inter-row application is just as effective if not even better (Table 32a and 32b).

Table 32 a. Effect of fertilizer placement on yield[a] in experiment 2

Year	Fertilizer placement on yield (tonnes/ha/year) Within weeded circle	 Outside circle	s.e. (±)	LSD 5%	Yield of control plot (tonnes/ha/year)
1970	22.56	24.49	0.91	1.88	20.98
1971	21.92	23.18	1.11	2.27	16.60
1972	22.39	23.18	1.58	3.24	13.19
1973	21.45	22.83	1.14	2.31	15.81
1974	25.13	25.18	1.61	3.29	19.36
1975	26.81	26.86	1.31	2.69	14.13
1976	23.62	23.75	1.78	3.66	8.89
1977	23.62	24.29	1.53	3.14	12.20
1978	22.68	24.68	1.11	2.25	16.60
1979	21.25	23.35	1.00	2.25	–
Mean	23.14	24.30			

[a] Yield 1969 – 23.02 tonnes/ha

Source: *Yeow et al. [1981]*

Table 32 b. Effect of methods of fertilizer application on yield in experiments 5-10

Experiment number	Year planted	Yield (tonnes/ha)									Mean (1977-1980)	
		Pre-treatment (1976)	1977		1978		1979		1980			
			(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
5	1970	28.10	30.28	29.79	28.37	30.22	27.13	27.58	33.66	33.68	29.86	30.30
6	1971	25.65	29.49	28.85	28.92	30.64	31.13	29.40	32.54	36.08	30.52	31.24
7	1971	30.57	33.65	31.84	33.85	33.00	30.37	35.83	26.38	25.60	31.06	31.57
8	1969	33.43	28.25	28.25	30.27	29.82	30.20	31.08	32.79	32.74	30.38	30.47
9	1969	32.72	28.52	29.21	22.19	19.52	27.68	28.84	29.85	32.20	27.06	27.44
10	1971	34.15	30.11	30.34	27.90	27.63	31.53	31.90	30.47	31.31	30.00	30.29
Mean expt. 5-10		30.77									29.81	30.22

(a) Conventional – fertilizer applied to every palm: placement within circle.

(b) Fertilizer broadcast along alternative avenues.

Source: *Yeow et al. [1981[*

Where labour is a constraint and terrain permitting, mechanical spreaders can be used, spreading the fertilizer on every second inter-row. One must, however, be aware of the danger of soil compaction especially where Ultisols prevail. Also, where labour is a constraint, the number of fertilizer rounds can be reduced.

An example of a fertilizer schedule for mature palms is given in Table 33.

Table 33. Fertilizer schedule for mature palms (9 years and older)
(kg of fertilizer per palm/year)

Urea	TSP/Rock phosphate	KCl	Kieserite	Borate
2.0 – 3.5	0 – 1.5	1.5 – 4.0	0 – 1.5	0 – 0.1

Note: In mature palms leaf analysis can be used as a reasonably rebliable guide. Proper pruning and thinning can be a precondition for high yield and good fertilizer (N and K) response.

8.4. Fertilizer use efficiency

To improve the efficiency of fertilizer use, *Ng [1977]* stresses the following points:

- appreciation of the nutrient balance concept in the palm age, development and productivity.
- improving techniques for the assessment of soil nutrient supplies and their exploitation, particularly in the case of potassium and magnesium.
- exploiting the symbiotic nitrogen fixation system through legume covers.
- minimizing nutrient losses via leaching by splitting heavy doses and putting them down during periods with low rainfall intensity.
- using the cheapest and most effective nutrient source (e.g. urea, ammonium sulphate or ammonium chloride for N, and reactive rock phosphate for P).
- spreading fertilizers to reach as large a surface area of the feeding roots as possible either within broad weeded circles or, where ground conditions permit, in the interrow in mature areas.

- maintaining a sound balance between major nutrients (for example between nitrogen and potassium, potassium and magnesium).

- paying greater attention to the micronutrient needs of oil palms, e.g. boron, and copper on organic soils.

- early recognition of problem areas such as acid sulphate soils and deep peat, adopting ameliorative measures at an early stage.

In addition, the following points may deserve special attention:

- to utilize the early yield potential of modern planting material it is important to avoid early depletion of soil nutrient reserves, which will result in later applied fertilizers becoming largely fixed in the soil until the deficits are rectified. In most cases it is prudent to "load" the palms with nutrients after the second year in the field. This is particularly important for potassium as the young palms have very little K-reserves in the storage tissue (trunk) and on coming into bearing, K reserves needed for high yield can easily be exhausted. Nutrient supplies for the second to fourth year should considerably exceed immediate nutrient needs of the palms.

- in areas with favourable climate (no moisture stress and high solar radiation) under good management it will pay to aim for maximum yields. Fertilizer rates should exceed uptake to assure sufficiently high concentrations of nutrients in the soil solution, and to allow for nutrient losses through volatilization, leaching and fixation.

- until a series of leaf analysis results and production data are available to fine tune fertilizer recommendations, it is usually better to err on the generous side of fertilizer application since it takes a long time to restore the yield of a palm depleted in nutrients and carbohydrates.

- under intensive cropping, soils in the tropics can undergo rapid changes in fertility and continued monitoring of such changes through soil and leaf analysis are important to maintain and improve yields.

- response to P and K are closely related with factors influencing the soil buffer capacity such as pH and clay content. pH may change rapidly as a result of applying acidifying fertilizer such as ammonium sulphate.

- fertilizer applied today will affect yields two years from now. It is therefore not wise to play "yo-yo" with fertilizer application, that is reduce fertilizer at times when palm oil prices are low and to increase rates when palm oil prices are high. Ommission or reduction of fertilizer application is particularly harmful in young palms (below 8 years in the field). Fertilizer rates for an economic yield as estimated from experiments conducted in Malaysia are shown in Table 34.

Table 34. Rates for economic "optimum" yield as estimated from 7 experiments in Malaysia

Expt. No.	Palm age (years)	Optimum fertiliser rates (kg/palm/year)[b]				
		S/A	CIRP	MOP	Kies.	Borate
1	4 – 6	4.72	2.54	3.36	1.68	0
	7 – 9	3.14	1.69	3.36	1.68	0
	10 – 11	5.03	0.88	4.05	2.03	0.09
2	4 – 6	3.63	1.99	5.76	2.61	0.03
	7 – 9	3.63	1.99	2.88	2.61	0.03
	10 – 11	4.61	2.92	3.00	2.80	0.05
3	4 – 6	4.02	2.11	1.62	1.01	0.05
	7 – 9	2.01	2.11	1.62	1.52	0.05
	10 – 11	3.75	2.25	4.15	1.17	0.06
4	4 – 6	3.60	0.94	2.28	0.86	0.06
	7 – 8	3.57	0.98	2.55	0.91	0.06
5	7 – 10	3.69	1.09	2.58	1.12	0.05
	10 – 13	2.40	0.74	2.16	0.70	0.09
6	7½ – 10½	4.95	2.67	4.00	1.88	0
	10½ – 13½	3.60	1.12	3.24	1.05	0.09

[b]S/A = Ammonium sulphate; MOP = potassium chloride;
CIRP = Christmas Island rock phosphate
Kies = Kieserite

Source: Adapted from *Tan et al. [1981]*

9. Concluding remarks

Although fertilizer is the largest cash expense item for most oil palm plantations, it is perhaps one item where wastage or unrealized gains are largest. On most estates there is still huge scope to increase yields through more efficient fertilizer use. On the one hand, an estate may spend considerable sums on leaf and soil sampling and analysis, fine tuning of fertilizer rates and the fertilizer itself, only to waste it through careless and negligent application.

The most common mistakes found in the field are:

- Incorrect method of application. Application of fertilizer in narrow bands or heaps instead of uniform spreading. This can cause severe damage to roots, and invites losses through leaching and run-off.
- Ill-timed application. Application where soil is too dry or too wet - affects N most.
- Insufficient application particularly to young palms.
- Imbalance between applied nutrients.
- Application zone not related to physiological age.
- Inaccurate application (doses not implemented correctly).

Apart from these basic mistakes, many planters and even research institutions still tend to look at fertilizer in isolation from the other components of oil palm management and agronomy. Some commonly observed inconsistencies found in the field are:

- Large doses of nitrogen applied to palms showing deficiency symptoms without any attempt to correct the underlying drainage problems.
- Large expenditure on lalang *(Imperata cylindrica)* eradication without any attempt to correct the underlying phosphate deficiency.
- Heavily fertilized palms are over-pruned during the immature stage.
- Precisely worked out fertilizer programmes applied without using calibrated measures.

Clearly optimum response to applied fertilizer can only be achieved when oil palm nutrition is integrated in a system of sound agronomy, crop husbandry, and soil management.

Research carried out by *Ng and co-workers [1977, 1983, 1985, 1990]* has shown that there is considerable scope for yield and income maximization through what he refers to as the Maximum Exploitation of the Genetic Yield Potential (MEGYP). This means developing high early yields, and maintaining peak yields over the longest possible period. This can only be achieved by the use of appropriate soil management techniques, the selection of good quality vigorous seedlings, and the maintenance of a productive balance between nutrition and leaf area index by timely attention to pruning, thinning and harvesting methods.

It is hoped that this book will contribute to a better understanding of the need for an integrated approach to management in order to reap the maximum return from the use of fertilizers in oil palms.

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