QUESTIONS RELEVANT TO REPLANTING IN OIL PALM CULTIVATION

J. D. FERWERDA

Dit proefschrift met stellingen van

JAN DIRK FERWERDA,

landbouwkundig ingenieur, geboren te Leeuwarden, 19 Juni 1917, is goedgekeurd door de promotor DR IR C. COOLHAAS, hoogleraar in de tropische landbouwplantenteelt.

De Rector Magnificus der Landbouwhogeschool,
W. F. EIJSVOOGEL

Wageningen, 23 Maart 1955

QUESTIONS RELEVANT TO REPLANTING IN OIL PALM CULTIVATION

PROEFSCHRIFT

TER VERKRIJGING VAN DE GRAAD
VAN DOCTOR IN DE LANDBOUWKUNDE
OP GEZAG VAN DE RECTOR MAGNIFICUS IR W. F. EIJSVOOGEL,
HOOGLERAAR IN DE HYDRAULICA, DE BEVLOEIÏNG,
DE WEG- EN WATERBOUWKUNDE EN DE BOSBOUWARCHITECTUUR
TE VERDEDIGEN TEGEN DE BEDENKINGEN
VAN EEN COMMISSIE UIT DE SENAAT
DER LANDBOUWHOGESCHOOL TE WAGENINGEN
OP VRIJDAG 29 APRIL 1955 TE 16 UUR

DOOR

JAN DIRK FERWERDA

H. VEENMAN & ZONEN - WAGENINGEN - 1955

Aan mijn ouders

STELLINGEN

(i)

Het planten van cacao onder oliepalmen of rubber maakt een ononderbroken gebruik van de grond mogelijk.

(ii)

De tussencultuur van sommige voedingsgewassen in oliepalmplantages gedurende enige jaren na het planten vermindert de kosten van aanleg en verhoogt de opbrengsten van de oliepalm.

(iii)

Bud Rot en Little Leaf bij de oliepalm zijn verschillende stadia van dezelfde physiologische ziekte, welke wordt veroorzaakt door Boriumgebrek.

(iv)

Vele oliepalmen in de Kwilu- en Kasai-districten van Belgisch Congo hebben de uiterlijke kenmerken van Magnesiumgebrek, Kaliumgebrek of beide. Het is mogelijk deze verschijnselen, welke gepaard gaan met lage opbrengsten, door doelmatige bemesting te voorkomen, waarbij behalve aan Magnesium en Kalium aan Borium gedacht moet worden.

(v)

Bij de waardering van gronden in de Kwilu- en Kasai-districten van Belgisch Congo voor de plantagelandbouw moeten topographie en vegetatie de doorslag geven.

(vi)

De steeds voortschrijdende ontbossing en het savanne branden versnellen de bodemdegradatie in Centraal Afrika. Intensieve voorlichting over een doelmatig gebruik van de grond en bevordering van de vee- en visteelt zijn de meest doeltreffende middelen om dit kwaad tegen te gaan.

(vii)

DEVUYST's conclusie dat een rationele selectie van oliepalmen op productie mogelijk is, door in het kweekbed van omstreeks éénjarige planten de hoogste uit te kiezen, berust op een onjuiste interpretatie van correlaties.

DEVUYST, A. Trop. Agric. Trinidad, 31, 2: 133–148 (1954)

(viii)

De waarde van oliepalmzaden, afkomstig van op uitzonderlijk onvruchtbare gronden geselecteerde moederbomen en pollenleveranciers, waarvan de nakomelingschap niet getoetst is, is zeer onzeker.

(ix)

De Afrikaanse oliepalm (*Elaeis guineensis* JACQUIN) is in hoge mate heliophiel.

(x)

De kiemsnelheid en de kiempercentages van oliepalmzaden verkregen bij het West African Institute for Oil Palm Research gedurende de jaren 1948–1953 zijn zeer onbevredigend in vergelijking met elders verkregen uitkomsten. Dit is waarschijnlijk een gevolg van een te lage temperatuur van de thermostatische kiemkamer.

WAIFOR, First Annual Report 1952–53: 50–52 (1953)

VOORWOORD - PREFACE

Landbouwkundig onderzoek verricht in dienst van een particulier bedrijf in Belgisch Congo is uiteraard niet gericht op het schrijven van een proefschrift. Dat U, Hooggeleerde COOLHAAS, Uw goedkeuring aan de bewerking van uitkomsten van mijn onderzoekingen voor een promotie heeft willen geven, stemt mij daarom tot grote erkentelijkheid. Uw belangstelling, critiek en medewerking hebben de voltooiing van dit werk mogelijk gemaakt.

Grateful thanks are expressed to the Board of Directors of HUILEVER S.A. for their generous gesture in allowing the writer to use the results of experiments carried out under their auspices in the preparation of this thesis. He is greatly indebted to Mr S. DE BLANK, Professor WARDLAW and Mr D. L. MARTIN for their encouragement and helpful criticism. He further wishes to express his acknowledgement to Mr J. JONNIAUX, Administrateur Délégué of HUILEVER S.A., for his keen and most encouraging interest in the progress of the writer's investigations.

Aan U, Zeergeleerde DE POERCK, ben ik veel dank verschuldigd voor de wijze waarop U mij hebt ingeleid in de vraagstukken van de oliepalmcultuur in Belgisch Congo.

The writer received most valuable help and assistance from the estate managers and their staff. They are too numerous to mention all individually, but he would like to single out particularly Mr ET. VERDONCK.

To his collegues Messrs. KOVACHICH and BROESHART the writer is greatly indebted for their helpful criticism and cooperation. Mr KOVACHICH provided the basis for the scientific observations on diseases. The chemical leaf analysis was carried out under Mr BROESHART's supervision.

Je tiens à remercier Messieurs COUDERE, DEVONDEL, DUPUIS, GREEN, SCIEUR et VREVEN, qui ont tous eu une part importante et essentielle dans l'exécution et la supervision des expériences discutées dans ce travail.

La plupart des observations de base a été faite avec beaucoup de zêle par Messieurs TAMPONI, MATARI et KIFUMBI, dont je leur remercie.

Gaarne maak ik gebruik van het voorrecht om op deze plaats dank te zeggen aan allen, die op enigerlei wijze hebben bijgedragen tot mijn vorming. Daarbij gaat mijn dank in de eerste plaats uit naar U, Hooggeleerde TENDELOO. Reeds tijdens mijn eerste studiejaar heeft U mijn belangstelling gewekt voor onderzoek.

Hooggeleerde VAN DER STOK en HUDIG, aan U dank ik mijn vorming tot landbouwkundige, waartoe ook wijlen Professor HONING veel heeft bijgedragen.

Zeergeleerde BRUIN en VAN DER PAAUW, aan U en aan wijlen Professor DE VRIES dank ik mijn vorming als landbouwkundig onderzoeker. De hartelijke geest van samenwerking en de waardering voor een ieders mening, welke ik tijdens mijn werk aan het Landbouwproefstation en Bodemkundig Instituut te Groningen heb leren kennen, zullen steeds in mijn herinnering blijven.

CONTENTS

CHAPTER 1. GENERAL INTRODUCTION

CHAPTER 2. SEEDBEDS

CHAPTER 3. NURSERIES

CHAPTER 4. EFFECT OF THE OLD STAND

CHAPTER 5. EFFECT OF FERTILIZING

CHAPTER I

GENERAL INTRODUCTION

1.1. ECONOMIC LIFE OF OIL PALM PLANTATIONS

1.1.1. The number of years during which oil palm plantations may be exploited economically depends on so many factors under African conditions of the industry, that an average figure would be of limited value. Some of the major factors determining the economic life are:

i) The height of the palms.
ii) The availability of skilled labour.
iii) The cost of harvesting.
iv) The production per hectare.
v) The cost of upkeep.

The importance of each of these is very different from region to region, and it is evident that they are to some extent related.

1.1.2. The height of the palms is probably the most important factor for many oil palm growing regions, because it determines whether a palm, with the available labour, still may be harvested or otherwise. Until the age of 12–13 years harvesting usually presents no particular difficulties, as the bases of the removed leaves enable to climb the palm without special means. After this period the leaf bases begin to fall off, from the middle of the trunk downwards and upwards, and climbing without the aid of a sling or a ladder becomes gradually impossible. In Malaya this difficulty seems to be partly overcome by the use of a specially designed harvesting knife, supported by a light stick, but our own experience with a similar tool tends to show that it becomes rather difficult to handle with palms which have over 8 metres of height.
The use of ladders in some regions of the Belgian Congo, consisting of a single bamboo pole, with the side branches cut back to a length of hardly 10 cm, is equally limited, as they become difficult to handle and to carry if their length exceeds some 11–12 m. This permits, under Yangambi conditions, to harvest a plantation during 19–20 years after planting (VANDERWEYEN 1952).

If harvesting with the aid of a sling is possible, however, the height of the palms will seldom or never determine the end of the economic life of a plantation.

1.1.3. The availability of skilled labour is a very serious problem in some plantations, whilst in others labour used to harvesting oil palms or willing to learn may be recruted locally or within reasonable distances. Men used to harvesting oil palms are found in those regions, where wild palm groves cover considerable areas, and palm oil is an essential part of the native diet. In other areas, however, the oil palm only plays a secondary rôle, and labour recruted from such regions is not always willing to learn the use of a sling. It is evident that the availability of labour able to climb with a sling determines the length of the economic life of a plantation to a high degree. If the palms have become too tall to be harvested by other means than climbing with a sling, the production per hectare becomes directly proportional to the number of cutters available per unit of surface, if this number falls below the minimum required to harvest all the fruit produced. Although the cutters are usually paid on task at this stage (number or weight of bunches), so that the cost of harvesting not becomes the limiting factor, this is not the same for the cost of maintenance of the plantations, including the upkeep of the roads, and the evacuation of the fruit.

1.1.4. The cost of harvesting per unit of surface increases with increasing age of the plantation if the potential production of the area remains more or less constant, because the number of bunches that a man can cut per day decreases with increasing height of the palms, and more specialized labour is required. Eventually the cost of harvesting the complete production becomes too high, depending mainly on the level of production and the density of producing palms, and normal exploitation is no longer economic.

1.1.5. The production per unit of surface is the product of the density of producing palms and their average production. The latter is the product of the average number of bunches and the average bunch weight. The average number of bunches per productive palm seems to decrease only very slightly after the 16th year under Yangambi conditions, whilst the average bunch weight continues to increase (VANDERWEYEN 1952). Consequently the average production per producing palm remains constant, apart from seasonal fluctuations, till at least the 20th year after planting under favourable conditions. Similar observations could be made in a 26 years old experimental plantation in the Kwilu region, but the relation only holds true for the approximately 50 per cent of the palms which survived at the end of this period. Under unfavourable conditions both the number of producing palms per unit of surface and their average production may decrease with increasing age of the plantation.

1.1.6. A number of fungal diseases is known to decrease the production of individual palms, and eventually to cause their death. Amongst these the following have the worst reputation in certain regions of the Belgian Congo:

i) Vascular Wilt disease, caused by *Fusarium oxysporum*, and first described by WARDLAW (1946). Although the havoc wrought by this disease is mainly limited to older palms, it may attack palms of all ages. It is widely spread in Nigeria and the Southern Congo (WATERSTON 1953, FRASELLE 1953, BULL 1954).

ii) Armillaria Root- and Trunk Rot, caused by *Armillaria mellea* (MOUREAU in VANDERWEYEN 1952, WARDLAW 1950) is rather frequent in the Northern Congo and mainly affects palms of 6–12 years of age. Its influence on production is limited, however, as the majority of the affected palms seem to recover without serious decrease of yield, and the percentage of palms dying as a consequence of the disease is relatively small.

iii) Ganoderma Trunk Rot, caused by *Ganoderna lucidum* (MOUREAU in VANDERWEYEN 1952), mainly affects palms over 20 years of age, and eventually causes their death. The disease is therefore of importance for the economic life of plantations in regions, where the harvesting of palms of this age is still possible.

Insect damage generally plays no important rôle in relation to the economic life of a plantation in the Belgian Congo. The presence of ants in the crown, however, may be the reason that a palm, although still producing, is no longer being harvested.

1.1.7. The chief diseases affecting the production per palm and the density of the stand are nutritional deficiencies. They lead in the case of the Plant Failures (WARDLAW 1946, ref. BULL 1954) to absolute and permanent improductivity, and in the case of the palms affected by the disease complex known as Bud Rot-Little Leaf (KOVACHICH 1952, 1953) at least to temporary, if not permanent, improductivity, and often to the death of the palm. The deficiency diseases will be fully discussed in Chapter 5, in relation to the problem of fertilizing in the case of replantings. Nutrient deficiencies are very common in oil palm plantations in certain regions of Central and West Africa, and may be the cause that the limits of economic exploitation of a plantation are reached long before harvesting becomes a technical impossibility.

1.1.7. The cost of upkeep is practically constant as long as the plantation carries a more or less full stand. Although the cost of ring- and pathweeding and interline slashing decreases with increasing age of the plantation, to become constant after the canopy has closed, this decrease is compensated by an increase of the cost of palm cleaning. If the production of the plantation decreases because a great number of palms dies or becomes permanently improductive, the cost of ringweeding and palm cleaning decreases, but as the canopy is no longer closed the cost of pathweeding and interline slashing usually will increase. The cost of upkeep as such, therefore, becomes seldom the factor limiting the economic life of a plantation, but only in relation to the production.

1.1.8. From the above considerations it appears that the economic life of a plantation can vary between wide limits. In the Kasai and Kwilu region of the Belgian Congo, where the conditions of soil and climate are extremely unfavourable, a successfully established plantation may become an economic failure because many palms die or become permanently improductive even before they have reached their maximum production. In the Northern Congo region, where the soils are usually better and the dry season is less severe, the impossibility of continuing harvesting usually determines the end of the economic life of a plantation, although the production may continue to be satisfactory.

1.2. PRO AND CONTRA OF REPLANTING

1.2.1. It is evident that as a matter of principle replanting of plantations, which have reached the end of their economic life, is more interesting than the opening up of new areas, because the cost of establishment is considerably lower. The cost of removal of the old stand is only a negligible fraction of the cost of making forest land ready for planting, and other important capital expenses as roadmaking and the construction of housing for the labour are avoided. Moreover, by means of an appropriate replanting technique, it may be possible to remove the old stand gradually if the latter is still producing satisfactorily and can still be harvested, so reducing the period of improductivity between the establishment of the replanting and its coming into bearing, and spreading the cost of upkeep during this time.

1.2.2. On the other hand it must be anticipated that the fertility status of the soil in the case of a replanting is usually lower than that of land previously covered by forest, which is only partially compensated by the nutrients released from the old stand after felling or poisoning of the latter. Depending on the nutrient reserve of the soil, which is not seldom extremely low under Congo conditions, a replanting may become successful with or without the aid of fertilizers. In old plantations in the Kwilu and Kasai districts it is no exception to find less than 50 ppm K in the top two metres of the soil, but in other regions the reserves may be considerable and are likely to meet most of the requirements of a replanting during its economic life.

1.2.3. Although nutritional deficiencies seem to predispose the oil palm to Fusarium Wilt (WATERSTON), it is obvious that it would be unwise to replant areas which are badly infected, as this disease is known to affect palms in all stages of development, and may cause heavy losses. Efforts are now being made to breed Fusarium Wilt resistant oil palms, but no planting material is available to date. Areas badly infected with *Armillaria mellea* are equally less indicated for replanting, although the havoc wrought by this disease rarely seems to surpass 12 per cent. *Ganoderna lucidum* infected areas can be considered as being suited, as this disease only seems to affect palms over 20 years of age (MOUREAU in VANDERWEYEN 1952), although the carpophores have been observed on young palms (KOVACHICH personal comm.).

1.2.4. Since it was realised that Little Leaf and Bud Rot are stages of the same physiological disease (KOVACHICH 1952, 1953) caused by boron deficiency (FERWERDA 1954), there is no reason to exclude those areas for replanting, where a high percentage of the palms died, or became permanently or temporarily improductive as a consequence of these diseases. The cost of applications of Borax are so low that they will always be justified.

Areas deficient in phosphorus, potassium and magnesium may only be recommended for replanting if a fertilizing programme is being adopted, as better planting material is not likely to exhibit its qualities on leached and degraded soils of an existing plantation. Although there is no doubt that responses to applications of phosphorus, potassium and magnesium may be obtained in relevant cases, as will be shown later (Chapter 5), and part of the expenses are justified by the saving in cost of establishment, it is evident that the economics of fertilizing depend largely on local conditions.

Since a better diagnosis of the symptoms of the major deficiencies became possible by means of a field experiment (Brab 49), a pot experiment (BROESHART 1955) and foliar analysis (BROESHART 1954a), it is clear that vast areas in the Kwilu and Kasai districts exhibit the extreme symptoms of boron, potassium and magnesium deficiency, and to a lesser degree of phosphorus deficiency. Other areas deficient in potassium were found in the Ingende Territory (District Tshuapa) and the Bumba Territory (District Congo-Ubangi). Phosphorus deficient areas were found in the Bumba and Basoko Territory (District Stanleyville). Boron and magnesium deficiency are less frequent in these areas, but everywhere present. From this it is evident that replanting of similar areas without appropriate fertilizing is bound to give disappointing results as compared to new extensions on good forest land.

1.2.5. Another important reason for replanting, even if an area has not yet reached the limits of its economic life, is the fact that the planting material available since 1942, originating from artificial Dura x Pisifera crossings by INEAC, gives a stand of 100 per cent Tenera with a production under conditions at least equalling those at Yangambi of approximately 2.600 kgs oil per hectare (VANDERWEYEN 1953). The planting material delivered until 1941, originating from Tenera × Tenera crossings, which was used for the establishment of the majority of the commercial plantations in the Belgian Congo, gave a stand consisting of approximately 25 per cent Dura, 50 per cent Tenera and 25 per cent Pisifera, the majority of the latter being sterile, and a production of approximately 1750 kgs oil per hectare under the same conditions. On the other hand it must be anticipated that the new type of planting material, which is now also being produced by one or two private companies following similar principles of breeding, is likely to have higher nutrient requirements than the old material.

1.2.6. An interesting feature in the breeding programme with respect to the economic life of a plantation and the desirability of replanting is the introduction of palms with a slow height growth. Although this is necessarily a long term programme, it is evident that the breeding of high producing palms with a slow height development is the surest means to lengthen the economic life of a plantation and to increase the interest of replanting areas where harvesting of tall palms becomes difficult or impossible. Some lines of *Elaeis guineensis* are known to have a considerably slower height development (VANDERWEYEN 1952, JAGOE 1952), whilst crossing with the related species *Eleais melanococca*, which has a much slower height growth than *E. guineensis* (VANDERWEYEN 1949, DE BLANK 1951) opens interesting possibilities.

1.3. OBJECT OF THIS THESIS

1.3.1. The technique of replanting has received little or no attention in the recent textbooks on the cultivation of the African oil palm (VAN HEURN 1948, VANDERWEYEN 1952). This is mainly due to the fact that the problem is relatively new. The possibilities for research on questions related to replanting did not obtain before 1930–40, because only then a number of plantations had reached the end of their economic life. Although the necessity of research was fully appreciated at that time, both in the Far East and in Africa, little experimental work could be done as a consequence of the abnormal conditions created by the war, and only recently the problems related to replanting are being studied more intensively in the various oil palm growing regions of the world.

1.3.2. In the Belgian Congo this work was initiated in 1948 at Brabanta (Basongo Territory) under the auspices of the Research Department of Huilever S.A., and now comprises seven field experiments. The results obtained to date from five of these are presented and discussed in this paper, the remaining two being only recently established. Full details concerning site, soil, design and lay-out of these experiments are given in the Appendix at the end of this paper. From this it appears that they allow for a study of the influence of the old stand (Brab 1, Yal 12), and of the combined and separate effects of various plant nutrients (all the experiments) on the young palms to be made, on three rather different soils in the Basongo, Basoko and Bumba Territories.

1.3.3. The main object of this paper is to provide a first basis for a sound replanting technique for oil palm plantations, by analysing the influence of the old stand (Chapter 4) and that of fertilizers (Chapter 5). It is evident that our conclusions are not meant to be a recipe for replantings in various parts of the world. They are only valid for the conditions of our experiments. Whether similar results may be expected in other regions requires a careful study of local conditions of soil and climate. This holds especially true for the effect of fertilizing, but to a lesser extent also for the effect of the old stand.

1.3.4. The seedbed technique for replantings is not principally different from that employed for new extensions, but a study of the literature reveals that little experimental evidence is available. Our seedbed experiments (see Appendix), designed to test the benefits of a number of standard practices, have shown, however, that the latter require revision in a number of cases. They are, therefore, discussed in Chapter 2.

1.3.5. The nursery technique for replantings may differ to some extent from that for extensions, in view of the fact that virgin land for the establishment of the nurseries is not always available in the vicinity of the areas to be replanted. The question may be raised, therefore, whether planting material may be grown in nurseries established under the canopy of old palms. At the same time it may be questioned whether germinated seed, or seedlings leaving the seedbeds, may be planted out directly into the field in the case of a replanting, as the canopy of the old stand may provide some protection and reduce the need for upkeep. Further the benefits of fertilizing in nurseries deserve attention, because of the presumed poor fertility status of areas to be replanted as compared to virgin land. These factors were studied in our nursery experiments, and discussed in Chapter 3. Details of the experiments are given in the Appendix.

CHAPTER 2

SEEDBEDS

2.1. INTRODUCTION

2.1.1. The current practice in the Belgian Congo is to plant out seed, which has previously been germinated, in seedbeds. These consist of 20–30 cm deep and approximately 1 m wide beds, filled with sand or soil. The seedlings remain here for a period, which usually does not exceed 3–4 months, and are then transferred to nursery beds.

2.1.2. Seedbeds are essentially the same as the original germination beds, and one might question whether they still serve a useful purpose after the introduction of a new germination technique. This point will be dealt with into more detail in Chapter 3. Here we will only discuss the optimum conditions for growing seedlings from germinated seed in seedbeds. This discussion will mainly concern a review of the results of our own experiments, as unbiassed evidence on the seedbed technique for oil palm appears to be very scarce.

2.2. GROWING MEDIUM

2.2.1. Formerly the use of sand as a growing medium in pre-nursery beds, and still more so for germination beds, was indicated in order to reduce the risk of insect damage. With potent insecticides available, however, a medium richer in plant nutrients and organic matter, and of a higher water capacity, e.g. the top few inches of fresh forest soil (terreau) might be used with advantage.

2.2.2. The results of our own experiments (Yal 14) fully confirm that terreau and a mixture of equal parts sand and terreau are outstanding growing media for oil palm seedlings, as compared to the customary coarse river sand, provided they are kept free from insect pests. Table 1 shows a detailed analysis of the development of the seedlings three months after planting out of the germinated seed on each of the above media.

From this it appears, that the growing medium has no influence on the percentage of the germinated seeds having produced at least one plantable seedling although the optimum density of the stand was reached somewhat earlier on terreau.

The number of plants produced per nut is independent of the growing medium.

2.2.3. The highest dry weight of the aerial part is obtained in pure terreau, immediately followed by a mixture of equal parts of terreau and sand. The growing medium affects the average number of leaves per plant, their length and their width, but the differences noted in the dry weight of the aerial part are mainly explained by the differences in the area of the second leaf. The length and width of the third leaf represent no direct measure for the effect of the treatments at this stage, as it was not fully developed, and even absent in many cases. As appears from the table, they are closely related to the average number of leaves per plant, or more precisely to the percentage of plants having three leaves (decimal places of the figures in the 4th row), as could be expected.

TABLE 1. YAL 14. INFLUENCE OF THE GROWING MEDIUM ON THE DEVELOPMENT OF OIL PALM SEEDLINGS IN PRE-NURSERY BEDS

	Observation	Sand	Sand + Terreau	Terreau	Sign. Diff. P = 0.05
1	Percentage of germinated seed having produced at least one seedling after: 3 weeks	17	34	27	
	4 ,,	35	54	52	
	5 ,,	68	68	83	
	6 ,,	89	95	92	
	7 ,,	94	97	94	
	8 ,,	95	97	95	
	9 ,,	95	97	95	
	10 ,,	96	97	95	
	11 ,,	96	97	95	
2	Number of plants per seed	1.09	1.10	1.11	
3	Dry weight aerial part (mg/plant)	394	555	596	23
	Do. as percentage of sand	100	141	151	6
4	Number of leaves per plant.	2.13	2.62	2.65	
5	Length leaves (cm) 1st	17.2	18.9	19.2	
	2nd	17.2	23.4	23.1	
	3rd	2.0	7.5	7.1	
6	Width leaves (cm) 1st	2.3	2.2	2.4	
	2nd	3.0	3.7	3.9	
	3rd	0.4	1.4	1.4	
7	Dry weight roots (mg/plant)	167	146	156	21
	Do. as percentage of sand	100	86	94	14
8	Number of roots per plant	1.45	1.68	1.74	
9	Length roots (cm) 1st	15.7	15.7	15.4	
	2nd	2.5	5.2	6.2	
	3rd	0.0	0.0	0.2	

2.2.4. The dry weight of the roots is not significantly different for the three growing media. It is interesting to note, however, that the number of roots is greatest on terreau, immediately followed by the mixture of sand and terreau. The length of the primary root is practically the same for all the treatments. The length of the first adventitious root (2nd root) is different, but it will be noted that this is closely related to the average number of roots per plant (the percentage of plants having two or more roots), and, therefore, no direct measure for the treatment effects.

2.2.5. From this it would appear that seedbeds should preferably be made from the black top layer of fresh forest soil (terreau) or a mixture of equal parts of sand and terreau if the latter is difficult to obtain. In order to prevent insect damage the beds should be treated with a suitable insecticide previous to planting, and this treatment should be repeated if necessary.

2.3. DEPTH OF THE SEEDBED

2.3.1. It is generally recommended to make pre-nursery beds approximately 20–30 cm deep (VANDERWEYEN 1952; BUNTING, GEORGI and MILSUM 1934) but we have been unable to find evidence supporting this recommendation. From a purely theoretical point of view it is somewhat difficult to see why, in the case of sandbeds, this layer should be much thicker than 10 cm to prevent insect damage. In the case of terreau, a similar depth would suffice, as the bulk of the roots are found in the top 10 cm.

2.3.2. The influence of the depth of the seedbed was investigated for beds composed of coarse river sand (Yal 16). The results are not tabulated, as the observations showed no differences whatsoever. From this it is apparent that the depth of the seedbed is of little importance, as long as it is deep enough for the development of the rooting system. No differences in growth were recorded between plants grown in layers of 10, 20 and 30 cm, 13 weeks after planting, under equal conditions of watering and shading. Therefore, taking the average length of the primary root into account, a depth, of 20 cm would appear to be largely sufficient to allow for a normal development of the seedling and for an easy removal of the latter without serious damage to its rooting system.

2.4. Shading

2.4.1. Light shading of pre-nursery beds is recommended during the dry season, until the young palms have produced their first functioning leaf. No shading would be required during the rainy season, and plantation practice in the Belgian Congo has proved that excellent results may be obtained in non-shaded seedbeds. Permanent shading of pre-nursery beds, however, has been common practice until recently, and is still practiced by a considerable number of oil palm planters. Therefore this point was included in an experiment (Yal 14) which comprised comparisons between temporarily (until the first functionning leaf showed) and permanent shading. The results are shown in Table 2. The experiment was performed during the dry season for this region, being a period with much sunshine.

It appears that shading has no effect on the early development, mortality and final number of germinated seeds having produced at least one plant. The number of plants per nut is slightly reduced by permanent shading.

2.4.2. The effect of permanent shading on the dry weight of the aerial part, however, is highly significant, resulting in a reduction of 21 per cent of the latter. This difference corresponds with a decrease of the number of leaves per plant, but there are only small differences in length and width of the leaves, and consequently of the leaf area, to be noted (for the third leaf see the note made in paragraph 2.2.3.). The decrease in the dry weight of the aerial part caused by permanent shading is somewhat greater than the corresponding decrease in leaf area, indicating that shading tends to decrease the dry matter content of the leaves, as could be expected.

2.4.3. The highest root production (dry weight) is obtained in absence of permanent shading, the latter causing a decrease of 33 per cent. This decrease corresponds with a decrease in the number of roots per plant and the length of the second root (first adventitious root).

From the above results it may be concluded that permanent shading cannot be recommended for pre-nursery beds, not even during dry periods with much sunshine.

TABLE 2. YAL 14. INFLUENCE OF SHADING ON THE DEVELOPMENT OF OIL PALM SEEDLINGS IN PRE-NURSERY BEDS

	Observations		Without shading	With shading	Sign. Diff. P = 0.05
1	Percentage of germinated seeds having produced at least one seedling after:	3 weeks	27	25	
		4 ,,	50	44	
		5 ,,	82	77	
		6 ,,	93	92	
		7 ,,	96	94	
		8 ,,	96	95	
		9 ,,	96	95	
		10 ,,	97	95	
		11 ,,	97	96	
2	Number of plants per seed		1.13	1.08	
3	Dry weight aerial part (mg/plant)		574	456	19
	Do. as percentage of without shading		100	79	3.3
4	Number of leaves per plant		2.60	2.34	
5	Length leaves (cm)	1st	18.9	18.4	
		2nd	21.1	21.4	
		3rd	7.1	4.5	
6	Width leaves (cm)	1st	2.4	2.2	
		2nd	3.6	3.5	
		3rd	1.4	0.7	
7	Dry weight roots (mg/plant)		187	126	17
	Do. as percentage of without shading		100	67	9
8	Number of roots per plant		1.74	1.50	
9	Length roots (cm)	1st	15.6	15.6	
		2nd	6.3	2.9	
		3rd	0.2	0.0	

2.5. SPACING

2.5.1. It is evident that the optimum spacing depends on the time that the plants will have to remain in the pre-nursery beds. As it is standard practice to transfer the seedlings to nursery beds when they have two fully developed leaves, which is the case after approximately three months under optimum conditions, we shall only consider the question of spacing for seedlings of this size. VANDERWEYEN recommends a spacing of 5 × 5 cm in his textbook (1952), which allows for 400 seedlings per square meter of seedbed. This spacing is generally found satisfactory in practice, although both narrower and wider spacings are in use. For open germination beds a somewhat wider spacing was recommended (BUNTING, GEORGI and MILSUM 1934).

2.5.2. The influence of the spacing was studied in beds composed of coarse river sand (Yal 16). The results are not tabulated because it appeared that the growth, mortality and final development of oil palm seedlings after 13 weeks is essentially the same for spacings of 5 × 5, 7 × 7 and 9 × 9 cm under equal conditions of watering and shading. Therefore the narrowest spacing can be recommended if one feels sure that the seedlings can be transferred to nursery beds in due time. This is nearly always the case if the latter have been established in time, are regularly watered, and provided with temporary shading. As the cost of the seedbed is only a negligible fraction of the cost of a plantable oil palm, however, it would be unwise to economise on the spacing if any risk is involved that the seedlings will have to remain in the pre-nursery beds for a period considerably longer than three months.

2.6. DEPTH OF PLANTING

2.6.1. VANDERWEYEN (1952) recommends to place the germinated seed 4–5 cm deep in the pre-nursery beds, and a similar depth is mentioned by other investigators (GEORGI *et al.*). It is not easy to understand why such a deep placement would be required for growing oil palm seedlings, apart from better moisture conditions during the early stages of development. These could easily be assured by other means, as regular watering and shading until the rooting system has firmly established.

In one of our experiments (Yal 14) three different depth of placement of germinated seed were included. The results are shown in Table 3.

TABLE 3. YAL 14. INFLUENCE OF THE DEPTH OF PLANTING ON THE DEVELOPMENT OF OIL PALM SEEDLINGS IN PRE-NURSERY BEDS

	Observations		Depth of planting			Sign. Diff. P = 0.05
			0 cm	2 cm	4 cm	
1	Percentage of germinated seed having produced at least one seedling after:	3 weeks	64	6	8	
		4 „	89	40	14	
		5 „	95	85	58	
		6 „	97	94	85	
		7 „	97	96	93	
		8 „	97	96	94	
		9 „	97	96	95	
		10 „	97	96	95	
		11 „	97	96	95	
2	Number of plants per seed		1.08	1.10	1.12	
3	Dry weight aerial part (mg/plant)		440	553	552	23
	Do. as percentage of 0 cm		100	126	125	5
4	Number of leaves per plant		2.67	2.39	2.35	
5	Length leaves (cm)	1st	13.6	18.9	22.9	
		2nd	17.1	21.4	25.1	
		3rd	7.2	5.5	4.6	
6	Width leaves (cm)	1st	2.4	2.3	2.2	
		2nd	3.5	3.7	3.5	
		3rd	1.4	1.2	0.6	
7	Dry weight roots (mg/plant)		187	150	132	21
	Do. as percentage of 0 cm		100	81	71	14
8	Number of roots per plant		1.68	1.63	1.56	
9	Length roots (cm)	1st	17.1	15.8	13.8	
		2nd	5.0	4.8	4.0	
		3rd	0.1	0.4	0.2	

The differences are very striking in the beginning, the shallow planted seeds coming up first, but the final density is the same for all the treatments. The number of plants per nut increases slightly with the depth of planting, but the differences are not significant.

2.6.2. The highest dry weight of the aerial part is obtained at 2 and 4 cms. The number of leaves per plant decreases with the depth of planting and is highest for the shallowest planting. Both length and width of the first and second leaves are increased by deeper planting. For the length and width of the third leaf, however, the same observation as made for the effect of the growing medium holds true. The corresponding increase in leaf area is somewhat greater than that of the dry weight of the aerial part for the deepest placement, indicating that deeper planting tends to decrease the dry matter content of the leaves.

2.6.3. The highest root production is obtained when the seed is only just covered, and rapidly decreases with the depth of planting. The same holds true for the number of roots (primary and adventitious roots) to a lesser degree, and the length of the primary root. For the length of the first adventitious root (2nd root) we refer to our observation in paragraph 2.2.3.

The differences noted in the dry weight of the roots are therefore mainly due to the differences in length of the primary root.

2.6.4. The results of this experiment are not conclusive regarding the optimum depth of planting. The highest dry weight of the aerial part is obtained at 2 cm, the greatest number of leaves per plant at 0 cm, the greatest leaf area at 4 cm, the highest dry weight of the roots at 0 cm and the greatest number and length of the roots equally at 0 cm. If the leaves may be considered as the most important part of the seedling, which is suggested by other evidences, it might be tentatively concluded that the optimum depth of planting is in the vicinity of 2 cm. Planting out trials are required, however, to determine the optimum depth of planting in seedbeds.

2.7. Time between removal from germinator and planting-out

2.7.1. It is recommended (Vanderweyen, 1952) to plant germinated seeds out in seedbeds immediately after their removal from the germinator. The standard practice is to reduce this time as much as possible, to avoid losses through dessication of the germ.

Although the common procedure seems reasonable, no direct experimental evidence is available to show that a delay of the planting-out of some hours, which regularly occurs, is a real malpractice or merely a hazard. To obtain this evidence this time-factor was included in an experiment (Yal 15). The results are shown in table 4.

It appears that the final number of seeds having produced at least one plant is approximately the same for all the treatments, the small differences not being significant. The same holds true for the number of plants produced per seed.

2.7.2. The dry weight of the aerial part of the seedlings is slightly reduced by a delay of the planting-out of 3 hours (10 per cent) and 6 hours (12 per cent). This reduction is mainly explained by a decrease in the number of leaves per plant and of the length of the second leaf, the length and width of the first leaf and the width of the second leaf being practically the same for all the treatments. The length and width of the third leaf are not taken into consideration for reasons set out in paragraph 2.2.3.

2.7.3. The time between removal from the germinator and planting out seems to have little or no influence on the dry weight, the number and the length of the roots.

From the above results it may be concluded that, although it is advisable to plant out germinated seed immediately after removal from the germinator, not much damage is done by a delay of as much as six hours on bright sunny days. Only a slight decrease in the dry weight of the seedlings may be noted, but not of their number. This is, of course, only on condition that the germinated seeds are protected from direct sunlight by covering them with leaves or another suitable means.

TABLE 4. YAL 15. INFLUENCE OF THE TIME BETWEEN REMOVAL FROM THE GERMINATOR AND PLANTING OUT

	Observations		Time		Sign. Diff. P = 0.05
		0	3h	6h	
1	Percentage of germinated seeds having produced at least one seedling after: 3 weeks	9	6	10	
	4 ,,	48	44	46	
	5 ,,	75	85	81	
	6 ,,	88	95	95	
	7 ,,	92	97	96	
	8 ,,	94	97	97	
	9 ,,	95	98	98	
	10 ,,	95	98	98	
2	Number of plants per seed	1.22	1.22	1.28	
3	Dry weight aerial part (mg/plant)	500	450	440	33
	Do. as percentage of 0	100	90	88	7
4	Number of leaves per plant	2.21	2.17	2.16	
5	Length leaves (cm) 1st	19.8	18.2	19.2	
	2nd	22.7	20.6	20.6	
	3rd	3.3	2.3	1.9	
6	Width leaves (cm) 1st	1.6	1.8	1.8	
	2nd	2.8	2.8	3.1	
	3rd	0.3	0.2	0.3	
7	Dry weight roots (mg/plant)	160	150	160	30
	Do. as percentage of 0	100	94	100	19
8	Number of roots per plant	1.60	1.50	1.56	
9	Length roots 1st	14.2	14.7	15.7	
	2nd	4.1	3.2	3.5	
	3rd	0.2	0.2	0.2	

2.8. SIZE OF THE GERMS

2.8.1. In order to avoid damage to the germs during the subsequent operations, it is recommended (VANDERWEYEN 1952) that the seed be removed from the germinator as soon as the embryo has emerged from the germ pore, still covered by its operculum, and before any further differentiation is apparent.

Although this procedure seems quite feasible and practical, no unbiassed evidence is available to show that planting out seed with a more differentiated germ is a malpractice. Evidence on this point has been obtained from experiment Yal 15, including comparisons between three different sizes of germs (fig. 1). The results are shown in table 5.

2.8.2. The first group contained the seeds, of which the germs were just visible, without or with only a slight beginning of external differentiation. The second group consisted of seeds with a germ clearly showing the radicle and the first (non functioning) leaf just coming out of the sheath. The seeds in the third group had a germ with a well developed, 5–10 mm long, root, with occasionally one or two secondary roots emerging around its collar, and the spear of the first non functioning leaf clearly showing.

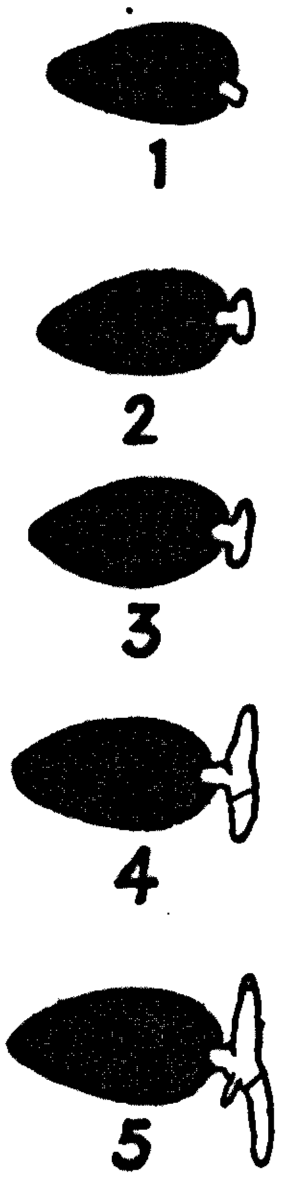

Fig. 1. Yal 15. Stages of development of the germ

2.8.3. It appears that the final number of germinated seeds having produced at least one seedling is approximately the same for all the treatments. The losses mainly occured in one plot, where 8 germinated seeds were damaged by ants. The differences are very striking at the start, the seed with the largest germ coming up first, but these differences are directly proportional to the small initial differences in the average age of the germs. It should be borne in mind that, in order to obtain germinated seed with different sizes of germs, the seeds were left in the germinator for a period of 10 days. Consequently the average age of the germ of group A was about one day, that of group B 5 days and that of group C 9 days. The differences in the rate at which the germinated seeds of the three groups produced seedlings with at least one functioning leaf were, therefore, not significant.

None of the differences between the treatments in average number of plants per nut reaches the level of significance. The average number of plants produced per 100 seeds amounted to 124, e.g. about 12 per cent of the surviving seeds having produced two seedlings.

2.8.4. The dry weight of the aerial part is significantly increased by planting out germinated seed with a clearly differentiated germ. For the largest germ as compared with the smallest one, this effect is of the order of 30 per cent. It is interesting to note that an increasing size of the germ corresponds with a decrease in length and width of the first functioning leaf, but an increase of the second and third leaf. Hence the beneficial effect of a large germ at the time of planting-out on the dry weight of the aerial part is not caused by a better initial growth of the seedling, as might be expected, but by a better subsequent growth.

2.8.5. The dry weight of the roots also increases with increasing differentiation of the germ at the time of planting out. The same trend is shown by the number of roots per plant and, consequently, by the length of the second root (= first adventitious root). The three sizes of germs have caused differences in the length of the first root. The differences in the dry weight of the roots are therefore mainly due to differences in number of roots.

2.8.6. The results of this experiment indicate that a seed with a germ clearly differentiated into rootlet and first non-functioning leaf is likely to produce better seedlings in the same period of time than seeds, of which the germ is only just visible with little or no external differentiation. This rather unexpected difference cannot be explained by taking into account the small differences in age between the germs at the time of planting out. The probable cause of the better results obtained with the larger germs is the fact that the seed can be orientated properly. If the embryo has only just pushed beyond the germ pore, no proper orientated planting is possible, and less than 50 per cent of the future roots will point downward. The energy required for rootlet and first non-functioning leaf to obtain the right orientation explains the difference found in final development. It is interesting to note that most of the energy is used for the actual

TABLE 5. YAL 15. INFLUENCE OF THE SIZE OF THE GERM ON THE DEVELOPMENT OF OIL PALM SEEDLINGS IN PRE-NURSERY BEDS

	Observations	Size of the germ [1]) 1	2 + 3	4 + 5	Sign. Diff. P = 0.05
1	Percentage of germinated seed having produced at least one seedling after: 3 weeks	0	17	23	
	4 "	11	48	79	
	5 "	67	82	93	
	6 "	88	94	96	
	7 "	94	96	96	
	8 "	95	97	97	
	9 "	96	98	98	
	10 "	96	98	99	
2	Number of plants per seed	1.28	1.17	1.27	
3	Dry weight aerial part (mg/plant)	400	470	520	33
	Do. as percentage of 1	100	118	130	8
4	Number of leaves per plant	2.11	2.14	2.28	
5	Length leaves (cm) 1st	20.3	18.7	18.2	
	2nd	18.5	21.8	23.2	
	3rd	1.6	2.0	3.9	
6	Width leaves (cm) 1st	2.0	1.7	1.6	
	2nd	2.6	3.0	3.0	
	3rd	0.2	0.2	0.4	
7	Dry weight roots (mg/plant)	140	150	180	30
	Do. as percentage of 1	100	107	129	22
8	Number of roots per plant	1.43	1.53	1.69	
9	Length roots (cm) 1st	14.8	15.2	15.9	
	2nd	2.2	3.5	4.5	
	3rd	0.02	0.12	0.75	

[1]) The numbers refer to the numbers in figure 1.

bending of the rootlet and the first non-functioning leaf itself, and not in a twisting of the portion of the embryo between the part containing the radicle etc., and the attached end of the haustorium (the future neck piece which connects the young plant with the nut). It is evident that the benefits of planting-out with a differentiated germ only hold true if the seeds are handled with care. On the other hand, it is our opinion that much damage is done to germs which are only just visible, as native labour tends to check upon the presence of the germ with the fingernail.

2.9. INTERACTIONS OF GROWING CONDITIONS

2.9.1. It is logical to expect that the effect of certain factors influencing the growth of oil palm seedlings in pre-nursery beds depends on the other conditions affecting the development of the young plant. Similar positive or negative interactions are likely to exist between growing medium, depth of planting and shading, the size of the germ and the time between removal from the germinator and planting out, the depth of the seedbed and the spacing, etc. The design of our experiments allowed for a study of the above mentioned interactions to be made, which may lead to a more precise foundation of the pre-nursery technique.

TABLE 6. YAL 14. INTERACTIONS BETWEEN THE EFFECTS OF GROWING MEDIUM, SHADING AND DEPTH OF PLANTING ON THE DRY WEIGHT OF OIL PALM SEEDLINGS IN PRE-NURSERY BEDS

	Shading						Average depths of planting		Average shading			Avarage depths of planting and shading
	Without			With								
	Depth of planting			Depth of planting			Shading		Depth of planting			
	0	2	4	0	2	4	Without	With	0	2	4	
Sand	375	470	404	330	358	424	416	371	353	414	414	394
Sand + Terreau . .	501	716	642	450	483	537	620	490	476	599	590	555
Terreau	536	726	793	446	568	510	685	508	491	647	652	596
Average media . . .	471	637	613	409	470	490	574	456	440	553	552	515

Significant differences for P = 0.05:

Medium × Shading × Depth	57
Medium × Shading	35
Medium × Depth.	40
Shading × Depth	35
Medium	23
Shading	19
Depth	23

2.9.2. It appeared from the analysis of variance that for yal 14 all the interactions between growing medium, depth of planting and shading are significant for the dry weight of the aerial part, that between growing medium and depth of planting being the least significant. It may be concluded that the influence of the growing medium is more pronounced in the absence than in the presence of shade (table 6), and greater when the seed is placed at 2 or 4 cm than with surface planting. The influence of the depth of planting is more evident in the absence than in the presence of permanent shading, but there is no significant difference between 2 and 4 cm. From an inspection of table 6 it appears that the highest dry weight was obtained on pure terreau with the seed placed 4 cm deep and without permanent shading. It is interesting to note, however, that even on coarse river sand the highest dry weights were obtained in absence of permanent shading, and with seed placed 2 cm deep. It is obvious that oil palm seedlings are very definitely heliophile.

2.9.3. For the dry weight of the roots only the interaction between growing medium and depth of planting is significant (table 7). The dry weight of the roots on pure terreau appears to be independent of the depth of planting, but both on sand and a mixture of sand and terreau the amount of roots rapidly decreases when the seed is placed deeper, especially in the case of sand.

2.9.4. From the above it might be concluded that the optimum depth of planting for pure terreau is in the vicinity of 4 cm in the absence of permanent shading, as the development of the rooting system is not affected by the depth of planting with an indication of an optimum at 2 cm. Confirming evidence from planting out trials are required to prove the correctness of this deduction, the optimum ratio between the aerial part and the roots being essentially unknown.

TABLE 7. YAL 14. INTERACTION BETWEEN THE EFFECT OF THE GOWING MEDIUM AND THE DEPTH OF PLANTING ON THE DRY WEIGHT OF THE ROOTS

	Depth of planting			Average depths
	0	2	4	
Sand	234	149	117	167
Sand + terreau	174	137	127	146
Terreau	152	165	152	156
Average media	187	150	132	156

Significant difference for P = 0.05:
Medium × Depth 37
Medium 21
Depth 21

2.9.5. The effect of the size of the germs, both on the aerial parts and the roots, appears to be independent of the time between removal from the germinator and planting out. This result is rather contrary to what could be expected, as a more differentiated germ would seem to be more susceptible to dessication when exposed to the surrounding air than a less developed one. The differences are too small, however, to allow for a conclusion to be made.

2.9.6. In the absence of positive main effects it was unlikely to find an interaction between the effects of the depth of the seedbed and the spacing. There appeared to be no relationship for any of the observations made between these two factors, as could be expected.

CHAPTER 3

NURSERIES

3.1. INTRODUCTION

3.1.1. The practice of growing planting material in seedbeds and nurseries, as opposed to planting germinated or ungerminated seed at stake, is so common for oil palms and many other plantation crops that its merits may seem to be beyond dispute. The establishment of seedbeds and nurseries is justified only, however, if the possible temporary or permanent damage done to the planting material by two or three successive transplantings is compensated in one way or another.

3.1.2. The advantages of growing planting material in seedbeds and nurseries are evident:

i) Shading, watering, mulching and fertilizing are more easily carried out and controled.
ii) The control of pests and diseases is easier.
iii) The facilities for the selection of healthy and vigorous planting material are greater.

The great disadvantage of establishing a plantation by means of planting out of ungerminated seed at stake is obviously a very irregular stand, due to the great differences in speed of germination between the individual seeds, but this could be overcome by using germinated seed. The control of pests and diseases would no doubt be more difficult than in seedbeds and nurseries, but not impossible. Selection of healthy and vigorous plants could equally well be done in the field, if a sufficient number of seeds were planted out at each point. Shading, mulching and fertilizing are more laborious, but still feasable. Only the watering would be a practical impossibility on an area of any considerable size.

3.1.3. Another objection which is often made against at stake planting is the lengthening of the improductive stage of the plantation. It is questionnable, however, whether this argument holds true when comparing the cost of the modern improved seedbeds and nurseries on a per ha basis with the cost of some 15 months extra upkeep of a plantation. Moreover it is not at all certain that the improductive period of a plantation would be lengthened by approximately the same time as required for growing planting material in seedbeds and nurseries, as the growth of the palms is not retarded by three times transplanting. Further at stake planting would improve the possibilities of intercultivation with annual or perennial catch crops, which has shown a beneficial and long lasting effect on the yield of the main crop in a number of cases (VANDERWEYEN 1952; BUNTING, GREGORY and MILSUM 1943; WAIFOR 1953).

3.1.4. In the case of a replanting, however, there would seem to be little advantage in at stake planting, unless the young seedlings would develop satisfactory under the canopy of the old palms. If this were true the extra cost of upkeep for at stake planting would be somewhat reduced, as only the ring weeding and disease control of the young palms would involve extra expenses.

3.1.5. In the case of areas for replantings and replacements nurseries were often established in the interlines of existing plantations, no fresh forest land being available in the vicinity. Although it was generally believed to be a malpractice as compared with nurseries established on freshly felled forest land, little or no unbiassed evidence is available. Thus ,if the poor growth of seedlings in nurseries under the canopy of adult palms as compared with those in nurseries on forest land is caused mainly by poor soil conditions, this disadvantage might be reduced or overcome by means of applications of compost and fertilizers. But if light proves to be the major factor limiting growth, the removal of adult palms, prior to planting the nursery, would be indicated.

3.2. Site of the nursery

3.2.1. The results of one of our experiments (Brab 7) allow for a direct study of the effect of the planting site on the development of the young palms to be made. The data refering to this section are summarized in table 8, in which A, B, C and D stand for:

Table 8. Brab 7. Influence of the site on the development

	A	B	C	D
Number of pinnae per frond	30.2	10.8	3.1	6.4
Length of the fronds (cm)	107	42	21	31
Distance between the pinnae (cm)	3.5	3.9	6.8	4.8
Mortality (per cent)	13	59	77	57

A. Nursery plants, grown from germinated seed planted in seedbeds, and transplanted to an open nursery on felled forest land when the seedlings were in the four-leaf stage.
B. Nursery plants, at the same growth stage grown from germinated seed planted in seedbeds, and transplanted to a nursery established in the interlines of an adult plantation.
C. Seedlings with four leaves, grown from germinated seed planted in seedbeds, planted directly in the area to be replanted under the canopy of the old palms.
D. Germinated seed planted at stake in the area to be replanted under the canopy of the old palms.

Inclusion of a nursery established in the interlines of an adult plantation after removal of the old stand would have improved the layout of this experiment.

3.2.2. It appears that the differences between the plants in the nursery on felled forest land (A) and the other treatments are enormous, although the latter also differ significantly from each other. Oil palm seedlings appear to grow much quicker, even without watering, when grown in open nurseries on forest land. It is interesting to note that the differences in number of pinnae per frond are greater than those in the length of the fronds, implying that the average distance between the pinnae is also different. Unfortunately the number of leaves produced could not be recorded, as an unknown number was removed when the plants were treated for *Cercospora*.

3.2.3. The above data leave no doubt that oil palm nurseries should preferably be established on unshaded land. In view of the poor growth and the high mortality of plants originating from four-leaf seedlings directly planted in the field and germinated seed planted at stake, even as compared to those grown from four-leaf seedlings transplanted to a nursery established in the interlines of an adult plantation under the canopy of old palms, it seems unlikely that these propagation techniques ever will be recommended as sound cultural practices for replantings. This is again illustrated by the average percentage of points without a single surviving seedling, amounting to 63 per cent for the four-leaf seedlings and 57 per cent for the germinated seed. Despite the fact that two seedlings and four seeds were planted per point, more than half became a complete failure. The percentage of the total number of seeds planted at stake which failed to produce a surviving seedling amounted to 78 per cent.

Planting at stake, however, compares favourably with planting out of four-leaf seedlings, and the results might be improved considerably by using germinated seed only instead of 25 per cent, as was the case in this experiment.

3.3. Compost and fertilizers

3.3.1. The benefits of applications of compost and fertilizers were studied in the same experiment (Brab 7). The compost consisted of well decomposed raffle, and was applied at the rate of 7 kg per palm, representing, when applied in a nursery, approximately 100 tons per ha. Fertilizers were applied three times with intervals of three months at the rate of 200 kg N, 114 kg P_2O_5, 220 kg K_2O, 114 kg MgO, 372 kg CaO, 50 kg copper sulphate and 5 kg borax per ha of nursery, and corresponding quantities (1/14,300th of the ha-application) for the four-leaf seedlings planted directly in the field and the germinated seed planted at stake. It will be noted that the fertilizer applications were rather high, and that the concentrations per point in the field (C and D) and in the nurseries (A and B) are the same. It was felt that this principle was sounder than applying the same amount of fertilizer per palm, as the actual concentration in the rooting zone is more important in the case of young plants than the absolute quantity available. There was a rather unfortunate, but instructive, experience at the time of planting out of the four-leaf seedlings. The soluble fertilizers, including phosphate as ammoniumphosphate, had been applied immediately before planting. Although it was raining at the time of planting out, it became evident a few days later that the plants of the fertilized plots, and particularily so those plots which had been planted first, had suffered badly from the fertilizer applications, and many seedlings died. As these losses were obviously due only to a faulty technique, viz. planting before the fertilizers had been adsorbed by the soil, so allowing the young and slightly damaged roots and occasionally the collar to come in direct contact with undissolved particles of fertilizer, they were immediately replaced. Fortunately an excess of planting material was available, so that replacements could be made following percisely the same principles as for the original planting.

3.3.2. Each of the propagation methods A, B, C and D discussed in the preceeding section (3.2) was subdivided for the following treatments:

1 Control (no fertilizers, no compost).
2 Fertilizing, no compost.
3 Compost, no fertilizing.
4 Fertilizing and compost.

The results obtained in the nursery on forest land (A) are summarized in table 9. From this it appears that both the application of fertilizers and compost, but particularly the former, have improved growth and slightly reduced the mortality. It is rather surprising to note that compost, even when applied on land previously covered by a rather heavy secondary forest, should still improve growth, but as it has no effect when applied together with fertilizers, its action must be due mainly to the plant nutrients it contains, and not to its organic matter content. It is still more surprising, however, that fertilizers applied on virgin land, previously carrying a dense forest improve growth by nearly 50 per cent (length of the fronds). This would seem to indicate that the nutrient reserve of the soil is very poor. The considerable amounts of nutrients released by the leaves and twigs after burning, although trunks and big branches were removed when clearing the land, together with the nutrients released from the decomposing roots, are insufficient to provide an optimum supply for the young palms throughout the whole of the period they remain in the nursery. In the present case no differences in development between the four treatments could be noted during the first 6–8 months after planting, suggesting that the major part of the nutrients released from twigs, leaves and roots becomes lost by leaching within this short period under these conditions.

TABLE 9. BRAB 7. EFFECT OF FERTILIZING AND COMPOST ON THE DEVELOPMENT OF PALMS GROWN IN AN UNSHADED NURSERY ON FRESHLY FELLED FOREST LAND

Observations	Treatments				S.D. 5%
	1	2	3	4	
Number of pinnae per frond	25.3	33.0	29.0	33.5	2.8
Length of the fronds (cm)	83	122	99	124	
Distance between the pinnae (cm) .	3.3	3.7	3.4	3.7	
Mortality (per cent)	15.2	12.0	12.3	11.1	

3.3.3. It is interesting to note (table 9) that the effect of compost and fertilizers is more pronounced in the average length of the fronds than in the number of pinnae per frond. Consequently the distance between the pinnae is somewhat greater for the composted and fertilized plots. It will be recollected (3.2.2., table 8) that the influence of the site of the nursery and the propagation method were more pronounced for the number of pinnae per frond. This would seem to indicate that the average frond length is a more sensitive indication of growth when dealing with palms under the same light conditions, but that the number of pinnae per frond is a more adequate measure when comparing palms of the same age, growing under different light conditions.

3.3.4. The effect of fertilizers and compost was also studied in a nursery established under the canopy of old palms. The results are shown in table 10.
The relative effect of fertilizing is of the same order as that on forest land, and the

TABLE 10. BRAB 7. EFFECT OF FERTILISERS AND COMPOST ON THE DEVELOPMENT OF PALMS GROWN IN A NURSERY ESTABLISHED UNDER THE CANOPY OF OLD PALMS

Observations	Treatments				S.D. 5%
	1	2	3	4	
Number of pinnae per frond	8.4	12.7	11.2	11.1	3.5
Length of the fronds (cm)	32.7	49.3	42.0	44.2	
Distance between the pinnae (cm) .	3.9	3.9	3.8	4.0	
Mortality (per cent)	43	73	52	69	

same holds true for the relative effect of compost. Both fertilizing and compost have increased the percentage of losses under these conditions, particularly the former. In an absolute sense, however, the effects of compost and fertilizing are much smaller than those in the unshaded nursery on forest land. If the difference between the nurssery on forest land and that under the canopy of old palms were mainly determined by a lower level of fertility of the latter, the contrary could be expected. The effects of compost and fertilizing are therefore highly dependant of one or more factors other than soil fertility in the present case. It would seem most likely that light is one of the major factors, as light is known to highly affect the growth of oil palm seedlings (2.4) and young palms (4.2).

TABLE 11. BRAB 7. EFFECT OF FERTILISERS AND COMPOST ON THE DEVELOPMENT OF FOUR-LEAF SEEDLINGS PLANTED OUT DIRECTLY IN THE FIELD, UNDER THE CANOPY OF OLD PALMS

Observations	Treatments				S.D. 5%
	1	2	3	4	
Number of pinnae per frond	4.2	2.4	2.9	2.9	1.1
Length of the fronds (cm)	23.5	18.9	20.1	20.3	
Distance between the pinnae (cm) .	5.6	7.9	6.9	7.0	
Mortality (percent)	63	85	75	86	

3.3.5. The effect of fertilizers and compost on the development of four-leaf seedlings planted out directly into the field under the canopy of adult palms is shown in table 11. Here the effects of both fertilizing and compost, but especially so of the former, are clearly negative. Compost seems to have reduced the harmful effect of fertilizing. A possible explanation for the negative effect of fertilizing is that the concentration of the fertilizer in the vicinity of the young seedlings has been too high. In the case of the nursery under palms the quantity per point was the same, but the actual surface on which the fertilizers were applied was greater because they were broadcast over the whole area, whilst in the present case they were applied within an area enclosed by a cercle with a diametre of about 60 cm. The negative effect of compost is probably due to induction of a more vigorous growth of weeds in the vicinity of the young plants, which in the field was less rigorously controled than in the nursery. The positive interaction between fertilizing and compost can than be understood as a reduction of the harmful effect of the excessive concentrations of fertilizers by a more vigorous growth of weeds.

3.3.6. Finally we give the effect of compost and fertilizers on the development of palms grown from seed directly planted out in the field (table 12).

TABLE 12. BRAB 7. EFFECT OF FERTILIZERS AND COMPOST ON THE DEVELOPMENT OF PALMS GROWN FROM SEED PLANTED OUT DIRECTLY IN THE FIELD

Observations	Treatments				S.D. 5%
	1	2	3	4	
Number of pinnae per frond	5.0	6.2	6.1	8.2	2.1
Length of the fronds (cm)	26.2	31.8	29.7	36.0	
Distance between the pinnae (cm)	5.2	5.1	4.9	4.4	
Mortality	58	72	51	47	

Both fertilizing and compost have improved growth over and above the control and their combined effect equals practically the sum of the single effects. The increase of the number of pinnae per frond is in this case more pronounced than in the length of the fronds, indicating that fertilizing and compost have considerably increased the growth rate. The decreasing effect of compost on the mortality is somewhat difficult to explain. It is probably due to the presence of seedlings, originating from seed contained in the bunch refuge from which the compost was prepared, which could not be distinguished from the seedlings originating from the seed planted at stake. This is also the probable reason why the effect of compost is positive, as opposed to the negative effect in the case of the fourleaf seedlings planted out directly into the field. The reason why the effect of fertilizing is positive in this case, as opposed to the negative effect in the case of the four-leaf seedlings, is probably that the seeds suffered less from the high concentrations of fertilizers than the four-leaf seedlings with their neccessarily slightly damaged rooting system at the time of planting out.

TABLE 13. YAL 10. INFLUENCE OF FERTILIZING ON THE LENGTH OF THE YOUNGEST FULLY OPENED LEAF OF NURSERY PALMS, ONE YEAR AFTER PLANTING. MAIN EFFECTS AND INTERACTIONS EXPRESSED AS A PERCENTAGE OF THE GENERAL MEAN (111 CMS)

Factor	Effect %
Nitrogen (N)	- 0.3
Phosphorus (P)	- 0.5
Potassium (K)	17.3
Magnesium (Mg)	- 5.5
Calcium (Ca)	1.2
Minor elements (Cu + Mg + B + Zn + Mb)	0.5
N × P	- 0.3
N × K	- 9.6
N × Mg	2.6
N × Ca	3.2
N × m.e.	- 0.7
P × K	2.3
P × Mg	- 0.9
P × Ca	10.6
P × m.e.	5.4
K × Mg	8.9
K × Ca	- 7.7
K × m.e.	1.9
Mg × Ca	- 6.4
Mg × m.e.	- 0.8
Ca × m.e.	- 3.4
Significant effect (P = 0.05)	6.0

3.3.7. From the above four experiments it may be concluded that fertilizing can be recommended as a general practice for establishing nurseries, as it is almost always of interest to obtain plantable plants as quickly as possible. There would be no advantage in applying compost in nurseries, as even heavy dressings show little effect, which disappears completely when fertilizers are applied at the same time. The above recommendations only can be made for the soil conditions prevailing in the Kasai region so far.

3.3.8. For the Congo-basin conditions the results of one factorial fertilizer experiment are available (Yal 10), which seem to suggest that on somewhat better soils the nutrients released from the twigs, leaves and roots together with the reserve in the soil are sufficient to provide an optimum supply for the palms during the time they remain in the nursery. A summary of the main effects and interactions expressed as a percentage of the general mean for various characteristics of the palms at the age of approximately one year is shown in table 13. From this it appears that the only positive significant main effect was that of potash on height. A greater height is known to correspond with an earlier production (see 4.2.4), and as the cost of fertilizing only represents a negligible fraction of the cost of a plant of plantable size, it is evident that even a very small increase in production will pay for the slightly higher cost of the planting material.

Chapter 4

EFFECT OF THE OLD STAND

4.1. Introduction

4.1.1. The ideal replanting procedure would be a system whereby the annual production from the replanted area never falls below that from the old stand, and surpasses the latter within the shortest possible period of time. This involves retaining of the potentially productive palms in the old stand until the young palms come into bearing, followed by a gradual removal of the old palms. The latter must be done in such a way that the sum of the annual productions from the old and young palms equals at least the annual productions obtained from the complete old stand, without affecting, however, the optimum development and productions of the young palms. Whether this is possible depends on the influence of the old stand on growth, disease incidence and production of the young palms.

4.1.2. Little information is available concerning the best replanting procedure. This is mainly due to the fact that the problem is relatively new. The oldest industrial plantations only reached the end of their economic life in the course of the period 1930–1940. One of the oldest trials, on which was regularly reported in the annual reports of the I.N.E.A.C. (INEAC, 1953), is probably the experiment established in 1934 at Barumbu (near Basoko, Belgian Congo). This includes comparisons between immediately replanting, replanting after two years fallow with *Mimosa invisa*, and replanting after one or two years of bush fallow of a completely felled old palmery. One of the immediately replanted areas previously carried a mixed plantation of old palms and cacao. Unfortunately the experiment consists of large single plots for each of the five treatments, which makes conclusions impossible because of the considerable differences in soil and topography. The yields in 1951 varied between 322 and 1289 kgs of oil per ha, without any sensible relation to the treatments.

4.1.3. Various replanting experiments were in progress in Malaya in 1940 according to a communication in the Malayan Agricultural Journal (1940), but they were probably abandoned because of lack of maintenance and observations during the war, as no results seem to be available.

4.1.4. Another replanting trial was established in 1951 at the Umudike farm, near Umuahia in the Owerri province, Nigeria (Waifor, 1953). The replanting was carried out in 5 acres of a 16 years old plantation under the canopy of the old palms, selected material being used and a dose of a not further indicated fertilizer mixture being placed in the planting hole. No treatment was given to the old palms at that time, but in June 1952 the following treatments were applied (five single one acre plots):

A All the leaves pruned;
B All the palms felled;
C Half the leaves pruned;
D Alternate N-S rows felled;
E Alternate E-W rows felled.

A fertilizer mixture was applied to the young palms at the same time. In January 1953 there were no outstanding differences between the five plots, but the period of time elapsed since the treatments were applied was rather short. The severely pruned palms had developed about ten leaves at that time. Although this is a non-randomized experiment without replications, the results may provide some valuable indications at some future date in comparison with similar experiments in other regions.

4.1.5. A more comprehensive replanting experiment was established in 1950 at the Federal Experimental Station at Serdang, Malaya (MALAYA, 1951, 1952, 1953, 1954). This includes the following whole plot treatments with four replications:

i) Felling before replanting;
ii) Felling one year after replanting;
iii) Felling two years after replanting;
iv) Felling three years after replanting.

A manurial experiment is superimposed on the main treatments, taking the form of a NPK-factorial design. Height measurements made on the young palms in November 1951 showed no significant differences. From this it would appear that retaining the complete old stand for a period of one year does not much harm, if any, to the development of the young palms under Serdang conditions. Later observations made in 1952 and 1953 tend to show, however, that if felling is delayed more than one year after underplanting, the growth of the young palms is seriously retarded. In the area where the old palms were felled prior to, and one year after replanting the young palms were beginning to flower in the course of the first months of 1953, whilst they were barely surviving in the other plots. From this it is already clear that the ideal of retaining the old stand until the young palms come into bearing cannot be realized under Serdang conditions. At least part of it must be removed in the course of the second year after replanting to assure a normal development of the young palms.

4.1.6. A similar but somewhat simpler experiment was laid down at Binga (Belgian Congo) by the Institut National pour l'Etude Agronomique du Congo Belge in 1951 (INEAC, 1953). It includes comparisons between the following treatments, with four replications:-

i) Felling before replanting;
ii) Felling one year after replanting;
iii) Felling two years after replanting.

Half of each plot is fertilized according to Homes' formula 3 (HOMES 1948) and half of each plot untreated. The first observations on the development of the young palms are known, but have not yet been published.

4.1.7. From the above it is clear that the present replanting technique as applied in practice on oil palm estates in Africa and the Far East is rather tentative and neither based on much experimental evidence nor experience, with the possible exception of the techniques applied by one or two companies on Sumatra, who dispose of private information from unpublished experimental results. MICHAUX (1953) in a review of the Far Eastern practice states that prior to replanting the standing palms are divided into three or four productivity groups. On the estates of the Société Financière this is being done by marking at intervals of six months on the stem of each palm the number of female inflorescences and bunches present in the crown during at least two years. In this period the area to be replanted is picketed and the planting holes are made and filled in. It is recommended to make large holes (90 × 90 × 90 cm). The reason for this is not quite clear, because it was shown by the INEAC (VANDERWEYEN, 1952) at Yangambi and Kondo in the Belgian Congo that small planting holes give exactly the same results as far as vegetative development and production of the palms are concerned as large holes, and require much less care when they are filled in. From this it may be concluded that there is no point in making the holes wider and deeper than required to contain the ball of earth of the plant.

The soil used for filling in is mixed with at least 10 kg, but preferably 30 kg of manure or compost and the fertilizers required for that particular soil. The new lines are picketed N-S between the old lines, so that the young palms come at equal distances from three old palms if the latter had a triangular spacing, or in the middle of the square if the latter had a square spacing. In the case of a faulty or undesirable spacing of the old stand the replanting is picketed independently from the latter. Old palms which are too close to a picket (minimum 2.50 m) are poisoned. The planting is done with big plants with a ball of earth. The young palms establish themselves very well under the canopy of the old stand, probably better than with complete removal prior to replanting. Whether this statement holds true for African conditions will be discussed in the following sections.

4.1.8. MICHAUX (1953) states further that 25–50 per cent of the old palms is removed by means of poisoning the palms with little or no production in the course of the first year after replanting, so reducing the old stand to 70–100 palms per ha. The decrease in the production of the old stand only amounts to 10–25 per cent if the palms are removed in this way. The remainder of the old stand is poisoned in the course of the following 2–3 years, with the object to bring the young palms into bearing 1–2 years after removal of the last old palms. The following schemes are in use:–

1st year	2nd year	3rd year	4th year
25%	12.5%	12.5%	50% or
33%	33 %	33 %	–

Palms which will be poisoned are subjected to a severe pruning in the course of the year previous to poisoning. The practice appears to have little effect on the ripening and the weight of the bunches that are already formed, but greatly reduces the development of new bunches.

In Africa no definite schedules for replanting seem to exist, the procedures adopted being largely based on the feeling of the managements of the estates. Both complete removal of the old stand prior to replanting, and replanting under the canopy of a completely or partly thinned out old stand, with subsequent thinning out, are in vigour.

4.1.9. The Far Eastern and African practice together with the few available experimental results tend to suggest that it is impossible to bring the young palms into bearing before complete removal of the old stand. The best replanting procedure that can be realized would therefore appear to be a system allowing for the maximum of benefit to be obtained from the old stand without affecting the normal development and production of the young palms.

4.1.10. THOMPSON (1940, 1941) has reported on an alternate system of rejuvenation tried out in Malaya, by cutting the roots on one side and pulling the tall palms over. The stems of some of the palms were mounded with soil up to the crown, others were not mounded. Two of the mounded palms died from stem-rot, but the remainder made new upright growth. It was found necessary to cut away all the fronds close to their point of attachement in order to avoid crowding and malformation of the new growth. Growth in all the palms was upright towards the middle of 1941, but flowering had not yet occured. The leaf bases of the mounded stems had decayed, and were full of palm roots throughout the length of the stems. These roots, however, were feeding roots of adjacent standing palms, and had not emerged from the buried stems, whose new root systems were confined to the original root forming tissue at the base of the stem. The stems of the majority of the felled, but unmounded, palms had decayed.

4.1.11. Similar efforts have been made in 1944 at the Ogba farm near Benin City in Nigeria (WAIFOR, 1953) on an one acre plot, in comparison with straight replanting after complete felling in the remainder of the area (four acres). Of the 65 'live' felled palms only 31 survived and eventually produced excellent crowns. Fruiting commenced in the course of 1947. The young palms, although they always looked healthy, have never grown well, which is probably due to a general nutrient deficiency. Harvesting was not commenced until 1949. Judging from the yield records for the period 1948–1952 live felling would not appear very attractive, but if the yields are expressed on a per palm basis they run very closely together with the replanted palms. This suggests that if live felling could be carried out with little or no losses, and if the severe pruning, which is known to seriously reduce the yielding capacity of the palms, could be shown to be unnecessary, it might still present some interest. Serious drawbacks of this system are in our opinion, even if a practically full stand could be obtained, the irregular stand, the greater chance on senility diseases (viz. Vascular Wilt and *Ganoderma*) and the poor 'planting material' in comparison with the present selections. Alternatively live felling could be restricted to those palms, whose actual production is already more than the average to be expected from a replanting with improved material.

4.1.12. The removal of the old stand as such presents no particular difficulties. Felling can be done by hand, but this is a costly and laborious procedure. Under Congo conditions one man may fell 5–12 tall palms per day, but 7 is already a good average. A further disadvantage of felling palms by hand is that orientated felling, which facilitates the picketing and lining, and reduces damage to the young palms in the case of felling after replanting, is more difficult to carry out. This is somewhat easier done by cutting the roots around the palm base, but this method is still more costly. It is, therefore, not surprising that efforts have been made to execute the removal of the old palms by other means.

4.1.13. HARTLEY (1948, 1949) has reported on two methods of felling oil palms by means of tractors, and further details were given in the previously cited replanting experiment at Serdang (MALAYA, 1951, 1952). One method consists of pulling the palms over with a 1 in. cable drawn by two HD10 Allis Chalmers tractors. Two rows may be felled by this method at a time, but in this case the palms fall inward and the work is less neat, several palms being incompletely felled. A cheaper method is pushing the palms over with a D8 Caterpillar tractor with stumper attachment. Under favourable conditions a palm may be felled in 20 seconds, the average time taken being 45 seconds. The latter method has the advantage of lifting the palm stump right out, but the former method is quicker in operation. Palms near drains or other obstacles can be pulled out, using a HD10 Allis Chalmers tractor and a winch. Both methods do very little damage to underplanted young palms, not even by hitting them with falling fronds. Mechanical felling of oil palms, however, requires heavy tractors, with consequent high cost of depreciation and repairs. It depends, therefore, on the efficiency, cost and availability of local hand labour whether mechanical felling may be recommended or otherwise.

4.1.14. Recently much cheaper methods of removing old or sterile palms by means of poisoning have been developed. HARTLEY (1949) and BUCKLEY (1951) reported that a palm may be killed by introducing 1 oz. of sodium arsenite in a hole bored into the trunk. Under Malayan conditions 1 oz. per tree was equally effective as 2, 3 or 4 oz. placed in the same number of holes. This experience could not be confirmed in series of trials established on the Main Station of the West African Institute for Oil Palm Research near Benin City (Nigeria) in 1952 and 1953 (WAIFOR, 1953). Doses of 1 oz. were found to have very little effect and the trees soon recovered. Even heavy doses of 6 oz., although killing the trees eventually, did so quite slowly, and there was no rapid disintegration of the trunk.

4.1.15. Our own experience obtained in the replanting experiments Brab 1 and Yal 12, however, fully confirms the Malayan results. Similar results were obtained by the research staff of a private company in Nigeria. In our first experiment 30 gm of dry sodium arsenite were introduced into two opposite holes, bored into the base of the trunk with a gentle downward slope towards the heart of the trunk. The majority of the treated palms showed the first effects of wilting after a period of only one week, and were completely dead within three weeks. Similar results were obtained with the introduction of 50 gm of a 45 per cent sodium arsenite solution into one hole in our experiment Yal 12.

With smaller quantities of this solution, however, many palms survived. It is interesting to note that later efforts to poison these treated palms remained without any result, and eventually they had to be removed by means of felling. All the resistant palms appeared to have cavities and necrotic areas in the vicinity of the auger hole, but they seemed to have developed a certain degree of resistance against the poison.

4.1.16. One man may easily poison 40 palms a day, and with suitable tools probably more. The holes may be made with ordinary carpenter's augers, but a crowbar works quicker. The first symptoms of the effect of the poison are yellowing and wilting of the leaves and bleeding from the hole and various other points of the trunk. The leaves then bend over in a way very similar to 'Leaf Bend' as described by LUC (1954), and eventually dry out. Later the whole crown breaks off, usually near the top of the stem, and falls down near the stem base. The trunk may remain upright for longer then a year, but eventually disintegrates and collapses rather than falling over. It is usually full of larvae of *Oryctes* and *Augusoma.*

Summarizing, we are of the opinion that poisoning with sodium arsenite is a sure and cheap method of removing old palms, although the technique would appear to require some further precision in view of the disappointing results obtained by the West African Institute for Oil Palm Research. It is not causing any mechanical damage to the young palms in the case of removing old palms after replanting, and has the further advantage of gradually exposing the young palms growing in the vicinity of a poisoned old palm to the full sunlight.

4.1.17. In the years before the war much attention was paid to the disposal of the felled or poisoned palms in a replanting, because it was feared that allowing the stems to remain on the surface to decay provided breeding facilities for one or two insects reputed as pests of the oil palm (THOMPSON, 1940). The latter practice was not considered to present the same danger from a mycological point of view, as harmful fungi only were found to develop fructifications on palms which were already affected prior to felling. It would appear necessary to destroy the larvae living in the decaying tissue of the stem before the life cycle of the insect is completed (also BUYCKX in VANDERWEYEN, 1952).

4.2. VEGETATIVE DEVELOPMENT

4.2.1. Observations concerning the influence of the old stand on the vegetative development of the young palms are available from our replanting experiments Brab 1 and Yal 12. The former allows for a study of the effect of a completely retained old stand during three years, the effect of fertilizing the young palms, and the interaction between felling and fertilizing to be made. The fertilizer treatment was included to obtain some preliminary information whether, if felling before replanting proved to be profitable, lack of light or poor soil conditions are the main cause of the failure on the non-felled areas. As appears from the description of the experiment (Appendix), the quantities of the various nutrients applied per palm and per annum have not always been the same. The subsequent modifications represent stages of increasing knowledge concerning the most economic formula for this region, as obtained from other experiments and investigations, and do not pretend to indicate the ideal nutrient supply for oil palm replantings of increasing age. Therefore the effect of fertilizing as discussed in the following pages, although already very important, represents by no means the optimum effect. This subject is more fully discussed in the next chapter (5).

4.2.2. The number of leaves produced per 100 living palms in the replanting experiment Brab 1 are summarized in table 14, giving the treatment averages, the main effects and the interaction for consecutive periods of six months after planting (four months for the first period). In order to facilitate comparisons between treatments the cumulative number of leaves produced per 100 living palms at various points of time after planting are illustrated in figure 2.

As appears from table 14, the leaf production per period of six months shows a steady increase with the age of the palm. There is, however, a decrease to be noted when comparing the period October-March with the immediately following period April–

September. The beneficial effect of felling the old stand previous to replanting on the leaf production of the young palms is already evident four months after planting, and increases with the age of the palm. The responses to fertilizing, however, only become noticeable in the leaf production 16 months after planting. The interaction between felling and fertilizing becomes positive 16 months after planting, indicating that the effect of fertilizing is greater on the felled than on the non-felled areas, but only reaches significance at the 5 per cent level for the period April–September 1950 (leaf count October 1950).

TABLE 14. BRAB 1. NEW LEAVES PRODUCED PER 100 LIVING PALMS PER PERIOD OF SIX MONTHS

Treatment	IV/'49 [1]	X/'49	IV/'50	X/'50	IV/'51	X/'51
No felling, no fertilizing . .	246	184	382	241	426	333
Felling, no fertilizing . .	317	248	582	484	822	725
No felling, fertilizing . .	240	172	516	297	660	489
Felling and fertilizing. .	296	250	818	677	1111	935
Sign. diff. P = 0.05 . .	34	35	99	38	95	121
Main effect felling . . .	64	72	251	312	424	419
Main effect fertilizing. .	–14	– 5	185	125	262	183
Interaction	– 8	7	51	68	27	27
Significant main effect or interaction P = 0.05 .	24	25	70	27	67	86
General mean	275	213	574	425	755	620
Standard deviation . . .	19	20	57	22	55	70
Standard deviation % .	7.1	9.5	9.9	5.2	7.3	11.3

[1]) Four months only.

It is interesting to note that the relative effect of felling is more pronounced in the period April–September (including the dry season for the region of Brab 1) than in the immediately preceeding period October–March. On an average, felling has improved the leaf production about twice as much as fertilizing, but the effect of both felling and fertilizing must be considered as very important.

Judging from the total leaf production (fig. 2) it appears that 34 months after planting (October 1951) the palms on the non-felled areas were on an average some 12 months behind in development as compared with those on the felled areas, whilst the non-fertilized areas were about 6 months behind as compared with the fertilized palms. The combined action of felling and fertilizing caused an improvement over and above the non-felled non-fertilized areas of 17 months.

4.2.3. Table 15 and figure 3 show the length of the youngest fully opened leaf after various periods of time in this experiment (Brab 1). Both felling and fertilizing have caused an increase of the length of the leaves from the 16th month after planting, and these effects increase with the time. There is, however, no indication of an interaction between felling and fertilizing so far as the length of the leaves is concerned.

Judging from the length of the leaves 34 months after planting (October 1951) the palms of the non-felled areas were on an average some 10 months behind in development as compared with those on the felled areas, whilst the non-fertilized palms were about 8 months behind as compared with the fertilized palms. The combined action of fertilizing and felling resulted in an improvement in development over and above the non-felled and non-fertilized areas of more than 19 months.

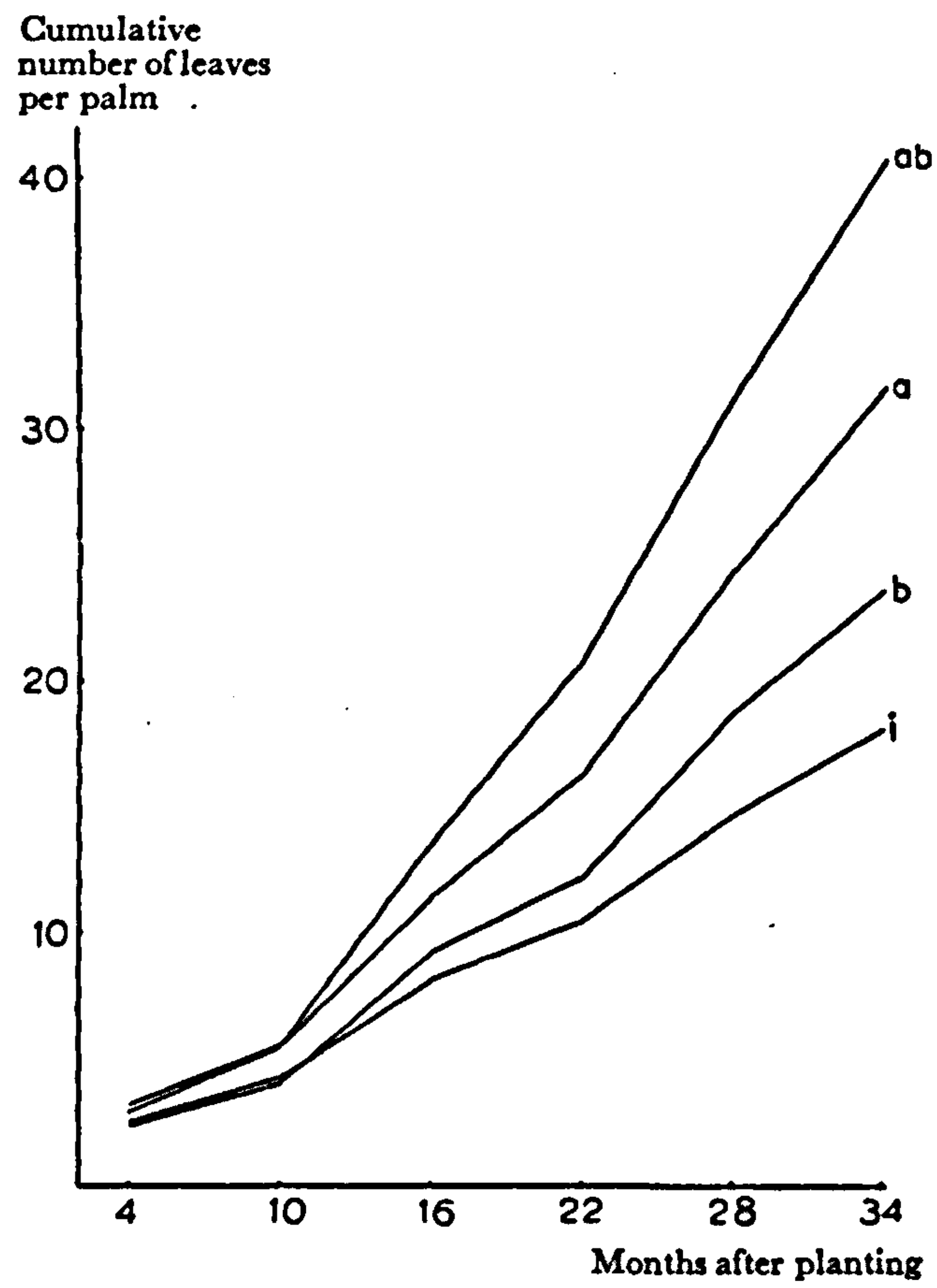

FIG. 2. BRAB 1. CUMULATIVE NUMBER OF LEAVES PER PALM AFTER VARIOUS PERIODS OF TIME

It is interesting to note that there is somewhat less difference between the effects of fertilizing and felling for the length of the leaves than for the number of leaves. This is due to the fact that better light conditions tend rather to increase the number of leaflets per unit of length of the leaf, than the length itself.

TABLE 15. BRAB 1. AVERAGE LENGTH OF THE YOUNGEST FULLY OPENED LEAF (CM)

Treatment	X/'49	IV/'50	X/'50	IV/'51	X/'51
No felling, no fertilizing	80	82	89	111	117
Felling, no fertilizing	86	100	109	159	193
No felling, fertilizing	85	104	102	145	156
Felling and fertilizing	87	125	126	193	238
Significant difference P = 0.05 . . .	15	12	15	25	26
Main effect felling	4	19	22	48	79
Main effect fertilizing	3	24	15	34	42
Interaction	–2	2	2	0	3
Significant main effect or interaction P = 0.05	11	9	11	17	19
General mean	84	103	106	152	176
Standard deviation	8.8	7.6	8.7	14.2	15.2
Standard deviation %	10.5	7.4	8.2	9.3	8.6

4.2.4. A somewhat more comprehensive series of observations concerning the influence of the old stand on the vegetative development of the young palms is available for the replanting experiment Yal 12. They allow for the study of the effect during one year of retaining the complete old stand, removal of one third by poisoning one third of the palms in all the lines, and removal of two third by poisoning one third in all the lines and felling alternate lines, to be made. It is evident that in the case of removing one third of all the palms only palms are selected with little or no production, so that the production per hectare from the old stand practically remains the same. As appears from the description (Appendix) the experiment further includes sub-plot treatments, viz. fertilizing of the young palms versus non-fertilizing, hoeing of the planting site prior to planting versus non-hoeing, and wide versus narrow spacing. As the subplot treatments are without any worthmentioning effect to date, only the whole-plot treatments will be considered.

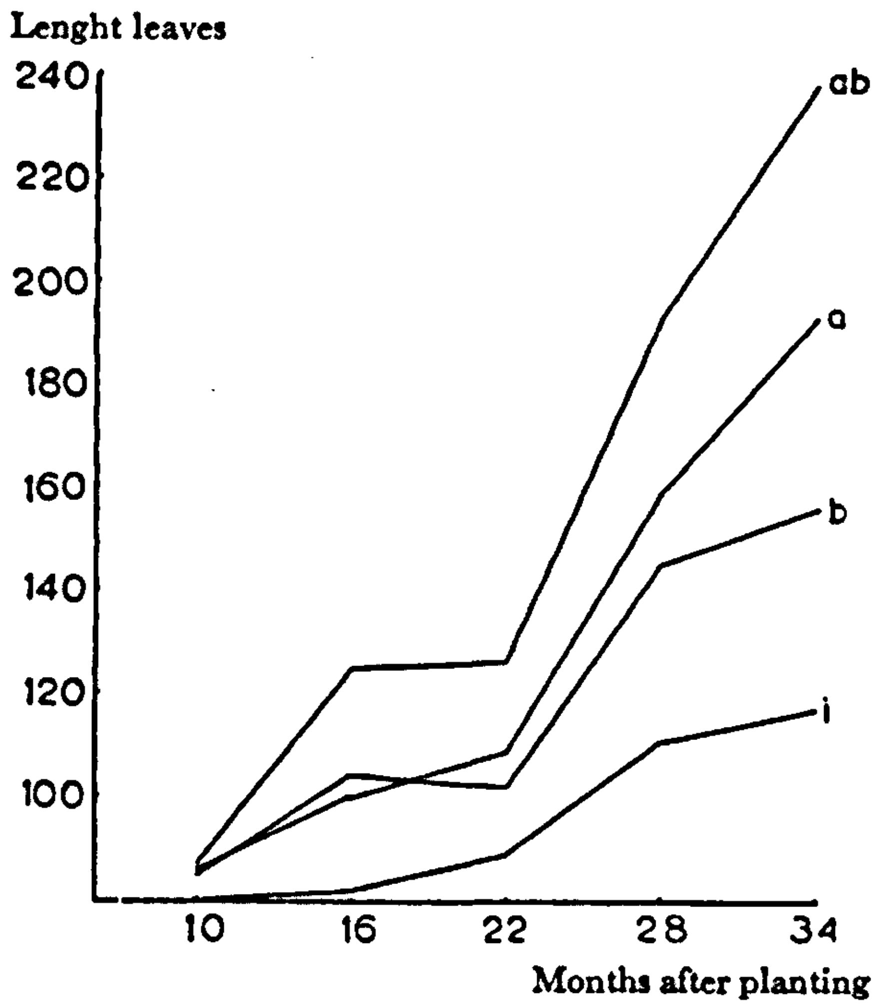

FIG. 3. BRAB 1. LENGTH OF THE YOUNGEST FULLY DEVELOPED LEAF AFTER VARIOUS PERIODS OF TIME AFTER PLANTING

4.2.5. The results of the series of observations made in Yal 12 are summarized in table 16. From this it is evident that the old stand has no influence on the length of the leaves during the first year after planting, as was the case at Brabanta. The number of leaflets per leaf, however, is significantly affected by the old stand and the same holds true for the length of the leaflets. The width of the leaflets, on the other hand, is independant of the presence or absence of the old stand during the first year after planting.

TABLE 16. YAL 12. EFFECT OF VARIOUS DENSITIES OF THE OLD STAND ON THE DEVELOPMENT OF THE YOUNG PALMS DURING THE FIRST YEAR AFTER REPLANTING

Observation	Removal of the old stand				S.D. 5%
	3/3	2/3	1/3	0/3	
Number of leaflets per leaf	107	100	98	86	5
Length of the leaves (cm)	149	147	152	142	–
Length of the leaflets (mm)	44	42	42	38	3
Width of the leaflets (mm)	2.9	2.8	2.8	2.8	–

The number of leaflets per leaf and the length of the leaflets appear to increase proportionally with the increasing percentage of removal of the old stand before replanting. This increase is somewhat more pronounced for the number of leaflets than for their length, the difference expressed as a percentage of no removal (0/3) being 24 per cent in the case of the number of leaflets and 14 per cent in the case of their length, between no removal (0/3) and complete removal (3/3).

It is evident that the increase of both the number of leaflets per leaf and their length cause an increase of the foliar surface. The latter may be estimated by calculating the products of the number and the length of the leaflets for each of the treatments, and expressing the relative foliar surface as a percentage of the calculated index for the foliar surface of the young palms growing under the canopy of the complete old stand. This estimation is an underestimation of the real increase of the foliar surface, because it is likely that the number of leaves increases also with increasing percentage of removal of the old stand (4.2.2). Although the latter could not be determined in this experiment, it may safely be assumed that the difference in number of leaves produced since planting between the non-felled and completely felled areas is of the magnitude of some 30 per cent, so that the real increase of the foliar surface due to complete removal of the old stand before replanting amounts to about 80 per cent. The estimation of the relative increase of the foliar surface based on the number and the length of the leaflets is shown in table 17.

TABLE 17. YAL 12. ESTIMATED RELATIVE INCREASE OF THE FOLIAR SURFACE DUE TO THE INCREASE OF THE NUMBER AND THE LENGTH OF THE LEAFLETS

Treatment	Foliar surface (%)
Old stand completely removed	142
One third of the old stand removed. . . .	128
Two third of the old stand removed . . .	127
No removal of the old stand	100

From this it would appear that removal of one third of the old stand before replanting already causes a considerable improvement in the vegetative development of the young palms in the course of the first year after replanting. The results suggest that some 2/3rd of the maximum possible improvement, as obtained by removing the old stand completely before replanting, may be achieved by removing only 1/3rd of the old palms. There would be little advantage in removing prior to replanting 2/3rd of the old palms as compared to the removal of 1/3rd.

4.2.6. The results of our replanting experiments Brab 1 and Yal 12 indicate that the presence of the old stand has a considerable influence on the vegetative development of the young palms growing under their canopy. This is already true during the first year after replanting as far as the number of leaves produced, the number of leaflets per leaf, and the length of the leaflets are concerned. The length of the leaves, however, seems not to be affected, which confirms the Malayan (4.1.5) experience. Even retaining as little as one third of the old stand for a period of one year after replanting, however, causes a significant decrease of the number of leaflets per leaf and of the length of the leaflets, and consequently of the foliar surface under Yaligimba conditions as compared with complete felling prior to replanting.

Retaining of the old stand for a period of nearly three years appears to cause a delay in the development of the young palms, which may be estimated at one year at the end of this period.

4.2.7. The effect of fertilizing in these experiments is nil during the first year after planting, but it would be premature to conclude that fertilizing has no influence on the vegetative development. It is evident that this depends on the nutrient conditions of the soil and the fertilizers applied, and in the case of partial or complete removal of the old stand prior to replanting on the amount of nutrients released from the decaying roots, leaves and stems. Positive responses to applications of nitrogen during the first year after replanting have been obtained in Malaya (MALAYA, 1952).

In the second and third year after replanting fertilizing very significantly improved the vegetative development of the young palms. Apart from the period April-September 1950 the effect of fertilizing was independent of the presence or absence of the old stand. This would seem to suggest that the beneficial effect of removing the old stand partly or completely prior to replanting is mainly due to the improved light conditions. A negative interaction could be expected if the beneficial effect of felling were mainly caused by the release of nutrients from the old stand, whilst no or a positive interaction would indicate that better light- or general climatic conditions are the cause.

4.3. DISEASE INCIDENCE AND MORTALITY

4.3.1. Although the census of the incidence of the various diseases is bound to be somewhat subjective, because the appreciation of different observers for essentially the same condition is likely to show variations, it nevertheless provides valuable indications of the differences existing at a certain time, and to a lesser degree also of the changes occuring in the course of the time. Observations on the disease incidence and mortality are available from our replanting experiments Brab 1 and Yal 12. The former provides a series of data covering the period December 1948–April 1954 (7 series of observations made with intervals of 6–12 months), the latter only one series (September 1954). The series of observations on the disease incidence and mortality for Yal 12 available to date provides little information concerning the influence of the old stand, because the mortality was negligible and the only disease symptom occuring sufficiently often to allow a comparison between treatments to be made was Orange Frond disease (BULL, 1954; FERWERDA, 1954; 5.2.5.).

4.3.2. The most important series of observations from a practical point of view concerns the percentage of healthy palms in Brab 1 (table 18, fig. 4). For Yal 12 these figures are not reproduced, because they are practically the complement of the incidence of Orange Frond disease.

The percentage of healthy palms on the non-felled areas was even higher during the first year after replanting than that on the felled areas, although the palms made less growth (4.2.2.). Fertilizing had no influence on the disease incidence. In the course of the second year both felling and fertilizing, but especially the latter have improved the percentage of healthy palms, although this still remained approximately on the level of the first year in the non-felled, non-fertilized plots. During the third year the health of the palms on the non-felled, non-fertilized plots decreased to a very low level, and this condition continued during the following years, with a slight improvement after removal of the old stand in the course of 1952. The beneficial effect of removing the old stand prior to replanting on the health of the young palms increased in the third year after replanting, and remained positive and on approximately the same level throughout the whole period of observation, even after removal of the old stand from the 'non-felled' areas (i and b). The effect of fertilizing, however, was rather irregular. After a considerable positive effect in the third year the response to fertilizing became negative or nil for the remainder of the period of observation as far as the percentage of healthy palms is concerned. This is entirely due to a sudden outbreak of Little Leaf disease (KOVACHICH 1952, 1953) in the felled and fertilized plots, as will be shown later (4.3.4.) and fully discussed in chapter 5 (5.2.7). The interaction between felling and fertilizing, absent during the first two years after replanting, became negative in the course of the third year and remainded so throughout the whole period of observation, indicating that the effect of fertilizing was negative on the felled, but positive on the non-felled areas as far as the percentage of healthy palms is concerned.

TABLE 18. BRAB 1. PERCENTAGE OF HEALTHY PALMS

	Oct. '49	Oct. '50	Oct. '51	Apr. '52	Apr. '53	Oct. '53	Apr. '54
No felling, no fertilizing	76	74	23	11	19	32	45
Felling, no fertilizing	59	84	70	64	73	82	82
No felling, fertilizing	75	89	64	36	32	56	37
Felling and fertilizing	57	96	72	24	27	58	69
Main effect felling	–14	8	28	21	25	25	34
Main effect fertilizing	– 1	14	21	– 7	–17	0	–11
Interaction	– 1	– 2	–20	–33	–29	–24	– 2

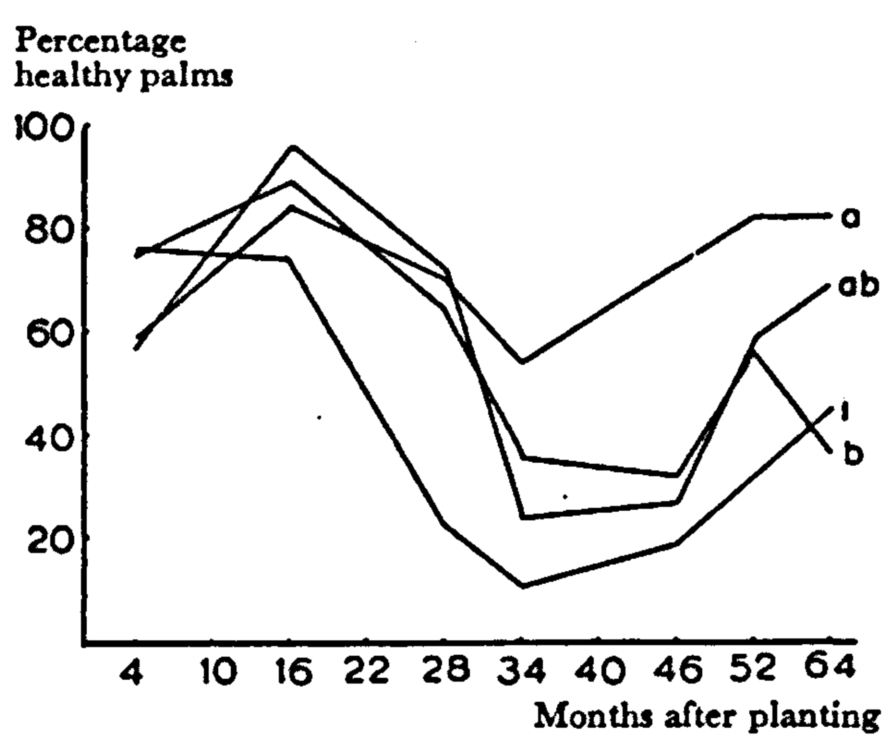

FIG. 4. BRAB 1. PERCENTAGE OF HEALTHY PALMS AFTER VARIOUS PERIODS OF TIME

4.3.3. Vascular Wilt disease of the oil palm, discovered by WARDLAW (1946a, 1946b, 1948, 1950a) and later described by FRASELLE (1953) and WATERSTON (1953) was little in evidence in the beginning, but eventually became the major disease on the non-felled and non-fertilized areas (table 19). Its incidence is reduced both by felling and fertilizing, suggesting that the external symptoms described as Vascular Wilt may have quite different causes, including growth disturbances caused by fungi and nutrient deficiencies. These possibilities will be more fully discussed in the following chapter (5.2 and 5.4).

TABLE 19. BRAB 1. INCIDENCE OF WILT PER 100 LIVING PALMS

	Oct. '49	Oct. '50	Oct. '51	Apr. '52	Apr. '53	Oct. '53	Apr. '54
No felling, no fertilizing	0	15	75	85	78	66	51
Felling, no fertilizing	0	4	25	21	14	15	12
No felling, fertilizing	0	7	34	27	26	15	12
Felling and fertilizing	0	2	12	10	12	13	12
Main effect felling	0	–8	–36	–50	–39	–26	–20
Main effect fertilizing	0	–5	–27	–24	–27	–26	–20
Interaction	0	3	14	13	25	24	19

4.3.4. Little Leaf and Bud Rot (KOVACHICH 1952) only became serious in April 1952 on the felled- and fertilized areas, and to a lesser extent also on the non-felled and fertilized plots. The results of the consecutive series of observations on the incidence of these diseases are shown in table 20. On the non-felled and fertilized areas the incidence of these diseases increased after removal of the old stand. It is obvious that the incidence of Little Leaf and Bud Rot is more or less related to the beginning of the productive stage, which is retarded by retaining the old stand, but it is equally obvious, as was already suggested by KOVACHICH (1953), that they are induced by a nutrient unbalance. It has been shown in the meantime (FERWERDA, 1954) that boron deficiency is the cause in the majority of cases (5.2.7). As boron was only once included in the fertilizer formula in very small quantities (see Appendix, Brab 1), and as borax is very soluble, it is not surprising that the palms never recovered from this deficiency, as effective curative measures only could be taken after discovery of the cause of Little Leaf disease in February 1954.

TABLE 20. BRAB 1. INCIDENCE OF LITTLE LEAF AND BUD ROT PER 100 LIVING PALMS

	Oct. '49	Oct. '50	Oct. '51	Apr. '52	Apr. '53	Oct. '53	Apr. '54
No felling, no fertilizing	5	4	0	4	3	2	2
Felling, no fertilizing	1	0	0	7	12	3	4
No felling, fertilizing	3	2	3	17	42	28	50
Felling and fertilizing	1	1	16	63	61	29	17
Main effect felling	–3	–2	6	24	14	1	–16
Main effect fertilizing	–1	–1	9	34	44	26	31
Interaction	1	1	6	10	5	0	–17

4.3.5. Orange Frond disease (BULL, 1954), which is now known to be caused by magnesium deficiency (FERWERDA 1954b; 5.2.4), was rather general during the first year after planting in Brab 1, especially on the felled areas. In Yal 12 the incidence of Orange Frond disease was entirely limited to the completely felled areas without fertilizing, so that there is no point in summarizing all the observations in a separate table. A more complete account of this disease is given in the following chapter (5.2.4, 5.4.4).

Other diseases were little in evidence (Patch Yellow, Plant Failure) and too few in number to be studied in relation to the treatments.

TABLE 21. BBAB 1. INCIDENCE OF ORANGE FROND DISEASE PER 100 LIVING PALMS

	Oct. '49	Oct. '50	Oct. '51	Apr. '52	Apr. '53	Oct. '53	Apr. '54
No felling, no fertilizing	20	8	2	0	0	0	1
Felling, no fertilizing	41	12	3	2	1	0	0
No felling, fertilizing	22	2	0	0	0	0	0
Felling and fertilizing	42	2	0	1	0	0	2
Main effect felling	21	2	1	1	0	0	0
Main effect fertilizing	1	–8	–2	–1	0	0	0
Interaction	0	–2	–1	–1	0	0	1

4.3.6. The cumulative mortality per 100 palms planted in Brab 1 is summarized in table 22. It appears that the death rate becomes very much lower after the 16th month after planting (April 1950).

TABLE 22. BRAB 1. MORTALITY PER 100 PALMS PLANTED

	Apr. '49	Oct. '49	Apr. '50	Oct. '50	Apr. '51	Oct. '51	Apr. '52	Apr. '53	Oct. '53	Apr. '54
No felling, no fertilizing	6	11	16	18	18	19	19	19	19	20
Felling, no fertilizing	4	5	6	6	6	6	7	6	7	–
No felling, fertilizing	7	10	17	18	20	20	20	22	23	24
Felling and fertilizing	5	5	9	8	8	9	12	12	14	–
Significant difference P = 0.05	2	8	8	5	–	–	–	–	–	–
Main effect felling	– 2	– 5	– 9	–11	–11	–12	–10	–11	–11	–
Main effect fertilizing	1	2	2	1	3	3	4	5	5	–
Interaction	0	0	1	1	0	1	2	2	2	–
Significant main effect or interaction P = 0.05	2	5	6	4	–	–	–	–	–	–
General mean	5	8	12	13	13	13	14	15	16	–
Standard deviation	1	6	5	4	–	–	–	–	–	–
Standard deviation %	26	73	39	31	–	–	–	–	–	–

The serious outbreak of Little Leaf disease (4.3.4) on the felled and fertilized plots, however, caused a new increase of the death rate. The same may be noted for the non-felled and fertilized plots after April 1953, which corresponds with the beginning of the productive stage of these areas.

Felling alone has caused a significant decrease of the mortality during the first three years after planting, the mortality on the felled areas being on an average some 11 per cent less than on the non-felled areas. The slight increase of the mortality caused by fertilizing during this period is not significant, but becomes so in the fourth year after planting. This undesirable effect of fertilizing must not be overestimated, however, as the formulae applied were purely tentative at the time and not necessarily correct for all the periods of growth.

The cause of the higher death rate on the non-felled areas is partly a purely mechanical one, the young palms being damaged by falling fronds from the old palms at harvesting or pruning. This damage may consist of damage to the heart of the palm, resulting in a spear rot, or an unilateral uprooting, the young palms being pushed over by the fallen frond and often dying after having shown external symptoms similar to those of Vascular Wilt.

Very similar experience was obtained in an unsuccesful replanting at Yaligimba. Although the deathrate was extremely high in this experiment, due to too deep planting with bare roots, and the use of rather oversized planting material, the percentage of replacements required on the areas where the old stand had been completely removed prior to replanting was still 14 per cent lower than that on the areas planted under the canopy of the old stand. The results are shown in table 23.

TABLE 23. YAL 12. PERCENTAGE OF LOSSES ONE YEAR AFTER PLANTING

Treatment	Losses	
	%	
Complete removal of the old stand	35	100
Two third of the old stand removed	38	108
One third of the old stand removed	39	111
No removal of the old stand	49	140

4.4. CHEMICAL COMPOSITION

4.4.1. The study of the chemical composition of living tissues to arrive at a better understanding of the physiology of cultivated plants has found its application to the oil palm industry through the work of CHAPMAN and GRAY (1949), a number of French investigators (IRHO, 1951, 1952, 1953) and BROESHART (1954a & b, 1955). Although the interpretation of the analytical data involves a number of difficulties, there is hardly any doubt that they provide a valuable tool for the extrapolation of the results of cultural experiments, particulary in the case of fertilizer experiments. Moreover they are a help for a better understanding of the results of the experiments themselves.

The influence of a completely retained old stand on the chemical composition of the interplanted palms was followed up in our replanting experiment Brab 1. The same experiment allows for the study of the effect of fertilizing and of the interaction between felling prior to replanting and fertilizing to be made. A similar series of data is available for our replanting experiment Yal 12, one year after replanting.

4.4.2. The phosphorus content of the laminae of the first fully opened leaf, expressed as a percentage of the ash in Brab 1 is shown in table 24. From this it appears that the phosphorus content is decreased by felling and fertilizing. This holds especially true for the first sampling, about three years after planting, and to a somewhat lesser extend also for the second sampling. The availability of phosphate in the soil, although sufficient as long as the growth is limited by poor light conditions and the deficiency of one or more other nutrients, seems to approach a minimum as soon as the growth is improved by means of removal of the old stand, providing both better light conditions and a supply of nutrients. It indicates also, however, that the fertilizer formula applied was not sufficiently rich in phosphorus. The P-content of the leaves on the felled and fertilized plots is low in an absolute sense (BROESHART, 1954a & b), and other experience (5.6.6) tends to show that positive responses to applications of phosphate may be expected at this level.

TABLE 24. BRAB 1. PHOSPHORUS CONTENT OF THE FIRST FULLY OPENED LEAF (PER CENT ON ASH)

Treatment	P-content	
	1951	1953
No felling, no fertilizing	6.8	5.0
Felling, no fertilizing	4.4	3.9
No felling, fertilizing	4.1	3.7
Felling and fertilizing	3.2	3.2
Significant difference for P = 0.05	0.7	0.7
Main effect felling	−1.6	−1.8
Main effect fertilizing	−1.9	−1.0
Interaction	0.8	0.3
Significant effect for P = 0.05	0.5	0.5
General mean	4.6	4.0
Standard deviation	0.4	0.4
Standard deviation (per cent)	9	10

4.4.3. The corresponding data for the first sampling in Yal 12 are summarized in table 25. No definite effect of the more or less complete removal of the old stand on the phosphorus content may be noted. Fertilizing, however, seems to have increased the phosphorus content slightly. The general level of the phosphorus content of the leaves in this experiment is low in an absolute sense, and it seems likely that responses to applications of phosphorus fertilizers will be obtained in the near future (see 5.6.6).

TABLE 25. YAL 12. PHOSPHORUS CONTENT OF THE FIRST FULLY OPENED LEAF (PER CENT ON ASH AND DRY MATTER)

Treatment	P-content	
	on ash	on dry matter
Old stand completely removed	3.12	0.221
Two third of the old stand removed	3.45	0.232
One third of the old stand removed	3.00	0.218
No removal of the old stand	3.17	0.236
Fertilized plots	3.28	0.240
Non-fertilized plots	3.10	0.214

4.4.4. The potassium content for the two samplings of Brab 1 are summarized in table 26. Felling of the old stand appears to have greatly increased the potassium content of the leaves, even more than fertilizing in 1951. The same deduction may be made from the absence of a response to felling in 1953, because removal of the old stand on the 'non-felled' areas has levelled out the differences between felling and non-felling as far as the potassium content of the leaves is concerned. The response to fertilizing is small and non-significant in 1953, because of the same reason. The interaction between felling and fertilizing is negative in 1951, indicating that the potassium content is very close to its maximum in the present case.

TABLE 26. BRAB 1. POTASSIUM CONTENT OF THE FIRST FULLY OPENED LEAF (PER CENT ON ASH)

Treatment	K-content	
	1951	1953
No felling, no fertilizing	19.4	25.3
Felling, no fertilizing	34.4	27.4
No felling, fertilizing	30.7	28.6
Felling and fertilizing	34.6	27.6
Significant difference for P = 0.05	4.4	n.s.
Main effect felling	9.4	0.6
Main effect fertilizing	5.8	1.8
Interaction	–5.6	–1.6
Significant effect for P = 0.05	3.1	n.s.
General mean	29.8	27.2
Standard deviation	2.4	3.3
Standard deviation (per cent)	8	12

4.4.5. The potassium content for the only available sampling of Yal 12 is shown in table 27. From this it appears that only complete removal of the old stand prior to replanting has materially increased the potassium content. This would seem to suggest that the uptake of potassium is dependent on the light conditions.

TABLE 27. YAL 12. POTASSIUM CONTENT OF THE FIRST FULLY OPENED LEAF (PER CENT ON ASH AND DRY MATTER)

Treatment	K-content	
	on ash	on dry matter
Old stand completely removed	24.9	1.77
Two third of the old stand removed	20.4	1.41
One third of the old stand removed	18.1	1.32
No removal of the old stand	19.1	1.47
Fertilized plots	21.2	1.57
Non-fertilized plots	20.1	1.41

4.4.6. Table 28 gives a summary of the magnesium content in Brab 1. This is significantly decreased by felling for the first sampling, because of the increased uptake of potassium released by the old stand. Although the external symptoms of magnesium deficiency (Orange Frond disease) had disappeared at that time (4.3.5), the above effect of felling explains the higher incidence of Orange Frond disease on the felled areas in the first year after planting. In 1953 the effect of felling was insignificant as far as the magnesium content is concerned, as could be expected. Fertilizing has slightly increased the magnesium content in the first period, which corresponds with the higher incidence of Orange Frond disease on the felled and non-fertilized areas in the second year after planting. At the time of the second sampling the differences are insignificant, as was the case for the incidence of Orange Frond disease.

TABLE 28. BRAB 1. MAGNESIUM CONTENT OF THE FIRST FULLY OPENED LEAF (PER CENT ON ASH)

Treatment	Mg-content	
	1951	1953
No felling, no fertilizing	4.2	3.6
Felling, no fertilizing	3.5	3.9
No felling, fertilizing	5.0	3.5
Felling and fertilizing	3.8	4.0
Significant difference for P = 0.05	0.4	n.s.
Main effect felling	-0.9	0.4
Main effect fertilizing	0.5	0.0
Interaction	-0.2	0.1
Significant effect for P = 0.05	0.3	n.s.
General mean	4.1	3.8
Standard deviation	0.2	–
Standard deviation (per cent)	6	–

4.4.7. A similar series of data is available for Yal 12 from samples taken approximately one year after replanting, which are summarized in table 29. From this it appears that the differences are small, although there is a tendency towards a decrease with increased removal of the old stand prior to replanting, and of an increase with fertilizing. The general level of the Magnesium content is much lower, however, than that in Brab 1.

TABLE 29. YAL 12. MAGNESIUM CONTENT OF THE FIRST FULLY OPENED LEAF (PER CENT ON ASH AND DRY MATTER)

Treatment	Mg-content	
	on ash	on dry matter
Old stand completely removed	2.41	0.171
Two third of the old stand removed	2.55	0.174
One third of the old stand removed	2.67	0.195
No removal of the old stand	2.42	0.181
Fertilized plots	2.54	0.187
Non-fertilized plots	2.48	0.173

4.4.8. The Calcium content for the two sampling periods of Brab 1 is shown in table 30. This is very different for the various treatments in the first period, due both to felling and fertilizing, and to a somewhat lesser extent also in the second period. The differences are closely related to the differences in potassium, magnesium and phosphorus content, and would not seem to require any further explanation at this stage.

TABLE 30. BRAB 1. CALCIUM CONTENT OF THE FIRST FULLY OPENED LEAF (PER CENT ON ASH)

Treatment	Ca-content	
	1951	1953
No felling, no fertilizing	14.0	11.1
Felling, no fertilizing	9.0	8.6
No felling, fertilizing	8.0	7.4
Felling and fertilizing	6.4	7.4
Significant difference for P = 0.05	1.9	3.4
Main effect felling	−3.3	−1.2
Main effect fertilizing	−4.3	−2.4
Interaction	1.7	1.2
Significant effect for P = 0.05	1.5	2.4
General mean	9.4	8.6
Standard deviation	1.1	2.0
Standard deviation (per cent)	11	23

4.4.9. Table 31 gives a summary of the calcium content for the only sampling period of Yal 12. The figures show the same trend as those for Brab 1 in so far as the effect of the old stand is concerned, although the differences are less pronounced, and are inversely proportional to the potassium content. The effect of fertilizing is negligible so far as the calcium content expressed as a percentage of the ash is concerned, and slightly positive when expressed as a percentage of the dry matter.

TABLE 31. YAL 12. CALCIUM CONTENT OF THE FIRST FULLY OPENED LEAF (PER CENT ON ASH AND DRY MATTER)

Treatment	Ca-content	
	on ash	on dry matter
Old stand completely removed	9.48	0.629
Two third of the old stand removed	11.08	0.751
One third of the old stand removed	11.49	0.837
No removal of the old stand	11.47	0.866
Fertilized plots	10.87	0.802
Non-fertilized plots	10.84	0.761

4.5. MALE AND FEMALE INFLORESCENCES AND BUNCHES

4.5.1. The average number of male inflorescences and of female inflorescences and fruit bunches present in the crown of a group of palms provides an early measure of their production and precocity. This measure is rather absolute in the case of the female inflorescences and bunches if the latter are recorded with intervals of approximately six months, but only a relative one in the case of the male inflorescences. Sixmonthly counts of the number of male inflorescences and of the female inflorescences and fruit bunches are available for Brab 1. Their number in Yal 12 is not yet sufficiently great to allow a comparison between treatments to be made, which is not surprising bearing in mind the age of the palms (1–2 years after planting).

4.5.2. The number of male inflorescences present at the end of each period of six months for Brab 1 are summarized in table 32. Figure 5 gives a picture of the cumulative number of male inflorescences, obtained by adding the average numbers of the consecutive sixmonthly counts. It should be borne in mind that the cumulative totals do not provide an absolute picture of the number of male inflorescences developed since the first observation. The first inflorescences were already present on the felled, and especially on the felled and fertilized plots before April 1951, but no census was made at that time because they were too small in number to allow for a comparison between treatments to be made.

It appears that both felling and fertilizing have increased the average number of male inflorescences present per living palms at each of the dates of observation, and that this holds especially true for felling. The effect of fertilizing has become small, however, after April 1952, which coincides with the high incidence of Little Leaf disease on the felled and fertilized plots. It is interesting to note that the average number of male inflorescences per surviving palm was already very high on the felled and fertilized plots in October 1951 and April 1952, and that the same average was never reached by any of the other treatments.

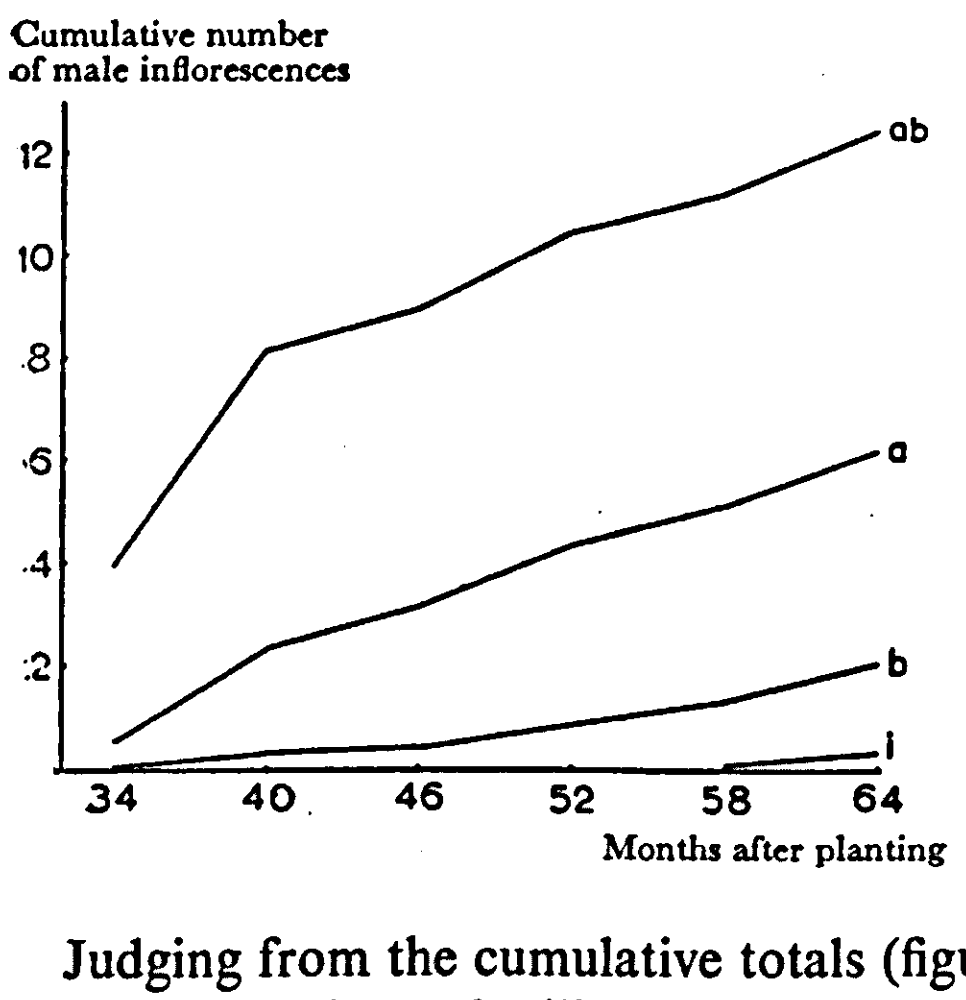

FIG. 5. BRAB 1. CUMULATIVE NUMBER OF MALE INFLORESCENCES AFTER VARIOUS PERIODS OF TIME

Judging from the cumulative totals (figure 5) the development of the palms on the non-felled and non-fertilized areas (i-plots) was, in April 1954, more than 30 months behind as compared with those on the felled- and non-fertilized areas (a-plots), and more than 24 months as compared with those on the non-felled fertilized areas (b-plots). Although the male inflorescences have not been counted before October 1951, our records show that they were present on the felled- and fertilized plots (ab-plots) as early as April 1950, suggesting that the combined effect of felling and fertilizing has advanced the maturity of the palms by at least 48 months. From this it would appear that the differences in physiological age existing in October 1951, as estimated from the cumulative number of leaves and the length of the leaves, were far more important for the future life of the palm than could be expected at that time.

TABLE 32. BRAB 1. NUMBER OF MALE INFLORESCENCES PER 100 LIVING PALMS

Treatment	Oct. '51	Apr. '52	Oct. '52	Apr. '53	Oct. '53	Apr. '54
No felling, no fertilizing	–	–	0	3	9	12
Felling, no fertilizing	56	178	83	116	75	105
No felling, fertilizing	8	28	11	41	46	76
Felling and fertilizing	392	422	82	149	70	119
Main effect felling	220	286	77	110	46	63
Main effect fertilizing	172	136	4	36	16	34
Interaction	164	108	–6	–2	–21	–20

4.5.3. In the course of the period April-September 1951 a number of palms on the felled and fertilized plots (ab-plots) commenced to produce female inflorescences and fruit bunches. This was the case for the felled, but non-fertilized plots (a-plots) and the non-felled, fertilized plots (b-plots) in the course of the following period of six months (October 1951–March 1952) and for the non-felled, non-fertilized plots in the period October 1952–March 1953. The number of female inflorescences and bunches present per 100 living palms for each of the four treatments at the end of the consecutive periods of six months are summarized in table 33.

TABLE 33. BRAB 1. NUMBER OF FEMALE INFLORESCENCES AND FRUIT BUNCHES PER 100 LIVING PALMS

Treatment	Oct. '51	Apr. '52	Oct. '52	Apr. '53	Oct. '53	Apr. '54
No felling, no fertilizing	–	–	1	2	9	30
Felling, no fertilizing	–	43	131	247	190	221
No felling, fertilizing	–	7	14	28	51	135
Felling and fertilizing	22	226	239	230	221	214
Main effect felling	11	131	178	223	176	134
Main effect fertilizing	11	95	60	4	36	49
Interaction	11	88	48	–23	–5	–56

4.5.4. It appears that the number of female inflorescences and bunches present at the end of each period of six months, which represents approximately the production during the immediately following six months, shows great differences between the various treatments. Both felling and fertilizing, but especially the former, have greatly increased production. This increase is for the greater part due to an earlier producing of the palms on the felled and fertilized areas, which is clearly illustrated by the data summarized in table 34, giving the percentage of producing palms at the end of each of the above periods. It is impossible to predict that similar differences will be obtained in the future, as the number of female inflorescences and bunches is known to reach an optimum after a certain period of time, which amounts to approximately 5–6 years under the conditions prevailing at Yangambi (VANDERWEYEN, 1952).

TABLE 34. BRAB 1. PERCENTAGE OF PRODUCING PALMS

Treatment	Oct. '51	Apr. '52	Oct. '52	Apr. '53	Oct. '53	Apr. '54
No felling, no fertilizing	–	–	0	1	2	9
Felling, no fertilizing	–	10	23	43	46	61
No felling, fertilizing	–	3	4	9	16	36
Felling and fertilizing	8	49	46	51	56	61
Main effect felling	4	28	32	42	42	38
Main effect fertilizing	4	21	14	8	12	14
Interaction	4	18	10	0	–2	–14

4.5.5. It will further be noticed that the rate of increase of production is considerably greater on the felled- than on the non-felled areas, and somewhat greater on the fertilized than on the non-fertilized areas. The first production worth mentioning on the non-felled, non-fertilized areas was obtained in April 1954, the production in the previous periods being limited to a small number of isolated palms, situated mainly near the limits of the felled plots, whilst the felled- but non-fertilized areas has reached the same stage two years earlier. When comparing the felled and fertilized with the non-felled and fertilized areas the same deduction may be made. The actual effect of retaining the old stand on the development of the young palms is therefore even worse than suggested by the retarded beginning of the productive stage. In fact the palms on the non-felled areas were in April 1954 at least two years behind in development as compared with those on the felled areas. The effect of fertilizing is somewhat less pronounced, but the number of producing palms on the felled and fertilized areas in April 1952 was approximately the same as that on the felled and non-fertilized areas in April 1953, suggesting that the difference in development had increased to approximately one year by that time. After April 1952 the number of producing palms and the average production per living palm was practically constant on the felled and fertilized plots, mainly as a consequence of the high incidence of Little Leaf disease. Moreover the number of bunches per palm is likely to reach its optimum in the course of the sixth year after planting under ideal conditions, so that only the total bunch weight and the cumulative number of bunches provide a direct basis for comparison after that time.

4.5.6. A good impression of the effects of felling and fertilizing may be obtained

TABLE 35. BRAB 1. CUMULATIVE NUMBER OF FEMALE INFLORESCENCES AND FRUIT BUNCHES PER 100 LIVING PALMS

Treatment	Oct. '51	Apr. '52	Oct. '52	Apr. '53	Oct. '53	Apr. '54
No felling, no fertilizing	–	–	1	3	12	42
Felling, no fertilizing	–	43	174	421	611	831
No felling, fertilizing	–	7	21	49	100	236
Felling and fertilizing	22	247	486	716	938	1151
Main effect felling	11	142	319	542	718	852
Main effect fertilizing	11	106	166	170	208	256
Interaction	11	99	146	124	119	63

from the cumulative number of female inflorescences and fruit bunches present at the end of the consecutive periods of six months, as these include the effects of previous periods and are not biased by the normal trend of the number of bunches per palm with increasing age. These data are shown in table 35, and moreover in figure 6.

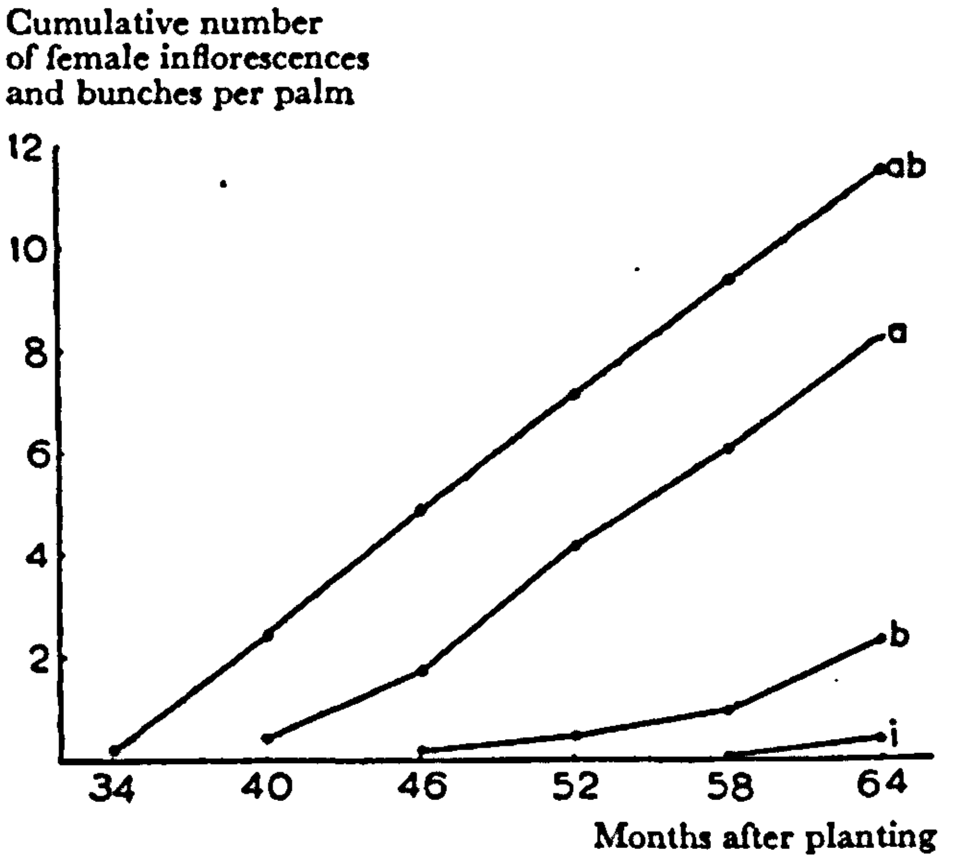

FIG. 6. BRAB 1. CUMULATIVE NUMBER OF FEMALE INFLORESCENCES AND FRUIT BUNCHES PER PALM AFTER VARIOUS PERIODS OF TIME

From this it is apparent that in comparison with the felled and fertilized plots (ab) the maturity of the felled but non-fertilized plots (a) was 12 months retarded in April 1954, that of the non-felled and fertilized plots (b) 24 months and that of the non-felled, non-fertilized plots (i) 30 months.

4.6. CONCLUSIONS

4.6.1. The results of our replanting experiments Brab 1 and Yal 12 show that the benefits of retaining the old stand for a certain period of time are greatly reduced by the increased mortality of the young palms, their poor and slow vegetative development, their greater susceptibility to pests and diseases, the retarded beginning of their productive stage and the slow increase in their production. In the case of the replanting experiment Brab 1 this reduction is likely to correspond with the economic value of at least two years of full production from the young palms. From the cumulative number of leaves produced at various points of time after replanting, representing more or less the physiological age of the young palms, it may tentatively be deduced that the benefits of retaining the old stand completely for various periods of time will be reduced by at least the economic value of the production obtained from the young palms during half that period of time. Even retaining as little as 1/3rd of the old stand during one year is likely to retard the maturity of the young palms.

4.6.2. The benefits of fertilizing the young palms will largely depend on the fertility status of the replanted area. It is evident from the results obtained in Brab 1 that they are somewhat reduced as long as the old stand is completely retained, but nevertheless very important. It seems likely that the effect of fertilizing will be intermediary if the old stand is partially retained, because of the reduction of the root competition and the improved light conditions.

4.6.3. In the case of Brab 1 the benefits of fertilizing were greatly reduced by an unforeseen minor element deficiency, which could only be corrected at the end of the period of observations covered by this study, after it was shown that Little Leaf is caused by boron deficiency. We have, therefore, good reasons to believe that the benefits of fertilizing would have been much greater if this disease could have been prevented in due time. It is suggested by the cumulative number of male inflorescences on the non-felled fertilized plots, which did not suffer seriously from Little Leaf disease in the period considered, and the same data for the female inflorescences and bunches, that a correct fertilizer formula is likely to affect the cumulative productions of the young palms in such a way that 1–2 years of full production are gained over a fixed number of years after replanting.

4.6.4. The results so far obtained do not yet allow for an evaluation of the effect of felling and fertilizing on the future production per hectare and per annum from the young palms to be made. It should be borne in mind, however, that non-felling increases the mortality and therefore the need for replacements, which is likely to reduce the maximum level of the future productions to some extent. Moreover experience tends to show that non-vigorous, backward, diseased young palms seldom become healthy productive adult palms. Fertilizing is likely to improve considerably the future productions under conditions similar to those of Brab 1, in view of the low fertility of the soil. This does not necessarily mean, however, that fertilizing will always be profitable for replantings, as the benefits depend largely on the nutrient conditions of the soil.

CHAPTER 5

EFFECT OF FERTILIZING

5.1. APPROACH OF THE NUTRIENT REQUIREMENTS

5.1.1. The first efforts to arrive at an estimation of the nutrient requirements of the oil palm were mainly based on the determination of the quantities of nutrients removed per hectare and per annum by means of chemical analysis and weighing of the various parts of the palm. Similar estimations were made by ZELLER (1911), MAAS (1922), GEORGI (1931) and WILBAUX (1937). It is evident that they are of limited value, and no direct measure of the nutrient requirements of oil palms growing under different conditions of soil and climate. They do, however, provide some amount of information concerning the immobilization of nutrients from soil and fertilizers after a given period of time.

5.1.2. The life of a plantation palm comprises four rather distinct periods, viz.:

i) The period until approximately 30 months after planting out in the field. During this time the externally visible growth is mainly limited to the crown and the rooting system.

ii) The period between 30 and 48 months after planting. During this time the growth of the crown and the rooting system continues. There is a beginning of the development of the stem, and the first male- and female inflorescences appear.

iii) The period between 4 and 7 years after planting. The development of the crown and the rooting system reaches its maximum towards the end of this period, the formation of new leaves and roots being balanced by those dying. The appearance of male and female inflorescences continues, and harvesting usually begins in the course of the fourth year after planting under favourable conditions in the Belgian Congo. The growth of the stem continues at a practically constant rate.

iv) The fourth period between 7 years and the end of the economic life of the plantation is characterized by a practically constant size of the living part of the crown and the rooting system, with a slight decrease towards the end of the economic life. The stem continues to increase in height at approximately the same rate. The number of fruit bunches produced per palm and per annum decreases, but the average bunch weight continues to increase, resulting in a practically constant total weight of bunches produced per palm.

It is likely, therefore, that the nutrient requirements of the oil palm are relatively small during the first period, considerably higher during the second period, still higher and reaching a maximum in the third period, and somewhat lower and practically constant in the fourth period.

5.1.3. The data provided by ZELLER (1911) for the chemical composition of roots and trunk, those by WILBAUX (1937) for the chemical composition of leaves and fruit bunches, those by RINGOET (1952) for the fresh weight of the crown and the yearly increase of the fresh weight of the trunk, and our own data for the dry weight of the rooting system (5.2.6), allow the following estimation of the quantities of plant nutrients immobilized per hectare by a 20 year old plantation of Tenera palms, planted at a density of 143 per hectare, and having produced approximately 196 tons of fruit bunches (VANDERWEYEN 1952) to be made (table 36):

TABLE 36. KGS OF NUTRIENTS IMMOBILIZED PER HA BY A 20 YEARS OLD PLANTATION OF TENERA PALMS, PLANTED AT 143 PER HA

	20 tons (dry) roots	139 tons (fresh) trunk	26 tons (fresh) crown	196 tons (fresh) bunches	Total
N	84	649	64	564	1361
P.	9.4	119	5.7	97	231
K	86	252	53	585	976
Mg	3.6	164	10	82	260
Ca	1.4	270	27	88	386

Without laying too much stress on the absolute amounts, because the data provided by ZELLER refer to the analysis of one single palm and those by RINGOET for the trunk are an estimation, these figures illustrate that the major part of the nutrients are stored in the trunk, and removed in the fruit bunches, the quantities stored in the roots and the crown being relatively small. It is interesting to note that the quantities of nitrogen and phosphorus in the trunk and in the fruit bunches are very much the same. The trunk contains less potassium, but more magnesium and calcium than the fruit bunches. The proportion of the nutrients is also very different for the various parts of the palm. The relative nitrogen content of the trunk and the bunches is much lower than that of the roots and the crown. The difference in composition of the roots and the trunk is very striking as far as the kations are concerned.

5.1.4. Assuming that the nutrients required for the roots and the crown are taken up in the course of the first seven years after planting, those for the trunk between 2½ and 20 years, and those for the bunches between 4 and 20 years, the following estimation can be made for the immobilization of nutrients per hectare for the various periods of the life of the oil palm (Table 37).

TABLE 37. IMMOBILIZATION OF NUTRIENTS PER PERIOD PER HECTARE

Age	N	P	K	Mg	Ca
0 – 2½	53	5	50	5	10
2½– 4	87	14	51	17	29
4 – 5	74	12	50	14	22
5 – 6	85	14	62	15	24
6 – 7	93	15	70	16	25
7 –20 (per annum) . .	74	13	53	15	21

From this it is evident that there is a considerable increase in the moderate initial nutrient requirements in the course of the third year after planting, corresponding with the beginning of the development of a trunk. The second increase corresponds with the beginning of the productive stage, and the highest demand for nutrients is likely to exist around the 7th year after planting, followed by a period of somewhat lower, and practically constant, requirements.

5.1.5. In the case of a replanting it may be admitted that the total quantities of nutrients shown in table 36 less those contained in the fruit bunches will be released after removal of the old stand. It is interesting to compare these amounts with those immobilized in forest fallow vegetations and grass, as determined by BARTHOLOMEW, MEYER and LAUDELOUT (1953). This comparison is shown in table 38.

TABLE 38. NUTRIENT IMMOBILIZATION IN OIL PALMS, FOREST FALLOW AND GRASS (KGS NUTRIENT PER HECTARE)

	20 years Oil palms	Forest fallow				Grass		
		17–18 years	8 years	5 years	2 years	*Pan.*	*Set.*	*Cyn.*
N.	797	701	579	567	189	374	378	463
P	134	108	35	32	22	37	55	52
K.	391	601	839	456	186	351	273	423
Mg + Ca	476	822	668	421	160	161	151	250

Pan. = *Panicum maximum*; *Set.* = *Setaria sphaceolata*; *Cyn.* = *Cynodon dactylon.*

The nitrogen immobilization by a 20-year old oil palm plantation would appear to be of the same magnitude as that of a 17–18 year old forest fallow. The same holds true for the phosphorus immobilization. The amounts of potassium, magnesium and calcium stored in the roots, trunks and crowns of oil palms, however, are comparable with those of a 5 year old forest fallow, and only half as much as those contained in the oldest forest. Even 3 year old grass fallows compare favourably with oil palms as far as potassium is concerned. The above data illustrate the interest of establishing oil palm plantations on land carrying a mature forest over and above a young forest fallow, a grass fallow or oil palms from a nutrient point of view. This is confirmed by the results of LOUVRIER's investigations (1951). From a practical point of view it might be questioned whether this advantage justifies the higher cost of establishment as compared with opening up land covered by a young bush fallow, grass or oil palms. The differences in nutrient immobilization could be easily overcome by means of fertilizing. It further seems probable that the amounts of nutrients applied as fertilizers required to compensate for the difference in nutrient immobilization are considerably less than the actual difference, because they may be applied at the proper time and the proper place, so reducing losses through leaching. It should further be borne in mind, as was pointed out by BARTHOLOMEW *et al.* (1953), that the process of decay of forest or fallow vegetation may not provide a balanced nutrient supply for the following industrial crop, but the same restriction may be made for an old stand of oil palms.

5.1.6. It is evident that the quantities of nutrients stored in roots, trunk, crown and fruit bunches only indicate the balance between the quantities taken up from the reserves in the soil, the decaying forest- or other vegetation and the fertilizers, and those returned to the soil as dead vegetative matter and ions. They are by no means a direct measure of the nutrient supply required to enable the uptake. The latter may be approached by studying the effect of various culture solutions. Similar experiments may only be realised for young palms, and do not, therefore, necessarily provide the information for fruiting palms. HOMES (1949) has studied the effect of 9 nutrient solutions, each providing the same total amount of nutrients expressed as equivalent-grammes, both for the kations (K, Mg, Ca) and anions (NO_3, SO_4, PO_4). Due to impurities of one of the salts the ratio anions/kations was somewhat different. The above solutions included the nine possible combinations of dominance of each of the kations and anions studied in the experiment. The observations comprised the height development, the diameter of the crown, the number of leaves, the degree of yellowing of the leaves, the fresh and the dry weight of the roots and the aerial part. The results indicate that the best growth was obtained by supplying the young palms with a nutrient solution of the following composition (table 39). Two of the other formulae, with the same proportion between the kations, gave nearly the same results, suggesting that the proportion between the kations is more important than that between the anions. Only one of the formulae with a different proportion between the kations gave similar results as far as the vegetative development is concerned, but the leaves were very yellow.

TABLE 39. HOMES' FORMULA 3

Equivalent grammes %		Convential per cent		Grammes nutrient	
K	12	K_2O	23	K	468
Ca	12	CaO	13	Ca	240
Mg	15	MgO	12	Mg	180
NO_3	37	N	21	N	518
SO_4	12	SO_3	19	S	192
PO_4	12	P_2O_5	12	P	124

It was originally suggested (HOMES, 1952) that this formula, and other formulae developed in a similar way for other crops, would provide a direct basis for the best fertilizer combination, independently of soil conditions. It is evident that this cannot be true in the light of the considerable body of knowledge available for a wide range of crops, showing that the nutrient requirements are closely related to the soil conditions. In the meantime it was admitted that the same relationship is likely to obtain for the oil palm (HOMES, 1954).

5.1.7. A considerable amount of work on the behaviour of seedling palms in nutrient solutions and pot cultures of various pH was done in Malaya. Although full details are not yet available, the reports on the current investigations (MALAYA 1950, 1951, 1952, 1953) suggest that the views as to the optimum pH for the oil palm require some amendment. It was shown that 20 months old seedlings grown in good jungle soil (pH 4.3), and the same soil limed to pH 7.0–8.0 (10 tons lime per acre) and pH 9.0–9.7 (20 tons lime per acre) respectively, eventually grew better on the soil limed to pH 7.0–8.0. In earlier experiments in nutrient solutions in a series at pH 3.5, 4.5, 5.5 and 6.5, however, the seedlings thrived best in the most acid solution. Increasing the magnesium content of the solutions rendered the plants more tolerant of higher pH. The results of these experiments would seem to suggest that there are two pH-optima for the oil palm, but confirmatory evidence from field experiments is required to make sure that this is the case under normal growing conditions. It is questionable, however, whether the extra expense for heavy liming would be profitable.

5.1.8. Considerable attention has been paid in Malaya to the effect of high concentrations of soluble aluminum in the nutrient solution. It was thought at one time that die-back and wilt were related to soil acidity or to soluble aluminum, in view of the fact that the aluminum content in the leaves of some field samples was found to be extremely high. Oil palm seedlings grown in hydroponic solutions containing up to 20.6 gms alumium sulphate per litre, however, evinced no signs whatever of distress. The aluminum content in the leaves did not quite reach the level of that in some of the field samples. It was tentatively concluded that wilt and die-back are neither caused by acid soil conditions nor by excess of soluble aluminum.

5.2. Study of the rooting system

5.2.1. An important aspect of the study of the nutrient requirements of the African oil palm under various conditions of soil and climate is the knowledge of its rooting system. The development of the latter, although being dependent itself on the conditions of soil and climate and the disease incidence (Yampolsky, 1922; Kovachich 1952a), determines whether nutrients available from reserves in the soil, decomposing vegetable matter and fertilizers may actually be taken up.

It may seem rather surprising that the knowledge of the rooting system of the African oil palm has been rather incomplete until recently. The studies of Vanderyst (1921), Yampolsky (1924) and Lambourne (1935) only deal in detail with the roots directly emerging from the trunk base, those developing on the trunk at some distance above the ground level, and the pneumathodes, and make no special mention of other roots. Wright (1951) in Nigeria has been the first to draw the attention to the existence of roots of a higher order. He observed that 2nd order roots emerge at almost right angles with irregular intervals from the roots directly attached to the trunk base. These secondary roots grow almost vertically, and a number of them, in fact the major part, are negatively geotropic, and reach the soil surface. Tertiary roots emerge at almost right angles from these secondary roots, and quaternary roots emerge from the tertiary roots. Tertiary and quaternary roots, although some are present throughout the whole soil profile to a depth of at least two metres, are very abundant in the top 10 cm of the soil, and form a thick mat.

5.2.2. Similar observations were made by Fremond and Orgias (1952). They observed that the number of secondary roots per unit of length of the 'primary' roots increases until 2–3 m from the trunk, and then decreases. The major part of the rooting system is found between 5 and 35 cm of depth. Prevot and Ollagnier (1953) state that only tertiary and quaternary roots absorb dyes (e.g. 1 per cent fuchsin), which tends to suggest that these, and not the 'primary' or secondary roots are the absorbing roots. For 11 year old palms the highest density of secondary roots is found between 2 and 4 m from the centre of the trunk base. From this it may be deduced that fertilizers should preferably be applied within the area enclosed by two concentric circles at 2 and 4 m from the centre of the trunk base.

5.2.3. On the whole our own investigations confirm the picture given by WRIGHT (1951) and the French investigators. One of the methods we employed for the study of the rooting system of oil palms was essentially the same as that employed by WRIGHT (1951). Profile pits, approximately one meter wide and one meter deep, were dug between the bases of two palms on opposite sides of the interlines. The walls of these profiles were sprayed with ordinary water under pressure from knapsack-sprayers, to wash out a few centimetres of soil and to make the roots visible without damaging them. This system gave satisfactory results for the topsoil, but was not effective for the subsoil under Yaligimba-conditions. Addition of ammonia to the water made the spraying somewhat more effective, but was stopped on account of the cost and the unpleasant working conditions created for the labour. On the much sandier soils at Brabanta, however, spraying with ordinary water was effective throughout the whole depth of the pit.

A second method used consists in taking samples of the same volume at various depth and at various distances from the palm with a soil sampler especially designed for the purpose. These samples are soaked in a 0.1 normal solution of a dispersing agent (ammonia, caustic soda), then placed on a 2 mm sieve and the soil washed away with water under pressure. The roots are retained by the sieve, and after removal of stones, debris and roots of other plants, dried and weighed.

A third method consists in removing a block of soil, approximately 1 m deep, 40–50 cm wide and 10 cm thick, from a profile wall. For this purpose 6–in. nails driven through a 1–in. plank are pushed into the profile wall, so enabling the block of soil to be removed without damaging it. This is placed with the plank downward in an open concrete tank and soaked with 0.1 N sodium hydroxyde for at least 24 hours. The soil can then be washed out with water under pressure, while the roots are kept in position by the nails. This method enables a complete picture of the rooting system to be obtained, but it is very laborious and not suited for mass investigations.

5.2.4. A photographic record of the result of one of our investigations employing the third method is shown in figure 7. This picture shows the roots contained in a block of soil removed just outside the clean weeded ring of a 11-years old palm at Yaligimba (Bumba Territory) in a good area.

5.2.5. The quantitative horizontal distribution of palm roots was studied in areas of various ages of planting by means of the second method. In each of these areas samples were taken from nine Tenera palms at distances of 1.00, 1.50, 2.00, 2.50, 3.00, 3.50, 4.00, 4.50 and 5.00 m from the centre of the palm. Table 40 gives a summary of the principal results obtained.

The average density for the various ages of planting shows considerable fluctuations, which cannot be explained as pure sampling errors. Part of these differences must be due to differences in growing conditions. The general trend seems to be that the

FIG. 7. ROOTING SYSTEM OF AN ADULT TENERA TYPE PALM AT YALIGIMBA

quantity of roots increases with age, the optimum density being reached before the 9th year after planting. For adult plantations the average dry weight of the roots contained in the top 10 cm of the soil is therefore likely to be in the vicinity of 2000 kg per hectare.

TABLE 40. DENSITY OF OIL PALM ROOTS IN THE TOP 10 CM OF THE SOIL AT YALIGIMBA (GMS DRY ROOTS PER SQUARE METRE)

Age of planting	Density	Distance from the palm	Density
13	244	1.00	202
12	160	1.50	200
11	263	2.00	192
10	150	2.50	197
9	224	3.00	165
7	113	3.50	165
5	97	4.00	167
		4.50	164
		5.00	158
Sign. diff. P = 0.05	11	Sign. diff. P = 0.05	13

A clear trend is shown by the rooting density in the samples taken at increasing distances from the centre of the palm. The quantity of roots per square metre in the top 10 cm of the soil between the palm base and 2.50 m from the centre of the palm appears to be approximately 20 per cent higher than that between 3.00 and 5.00 m.

5.2.6. The vertical distribution of the roots of 10 years old Tenera palms under Yaligimba conditions is shown in table 41.

TABLE 41. VERTICAL DISTRIBUTION OF THE ROOTING SYSTEM OF 10 YEAR OLD TENERA PALMS AT YALIGIMBA, EXPRESSED AS A PERCENTAGE OF THE TOTAL DRY WEIGHT TO A DEPTH OF 1 M

Depth (cm)	Per cent	Cum. per cent
0– 10	11	11
10– 20	13	24
20– 30	19	43
30– 40	11	54
40– 50	11	65
50– 60	10	75
60– 70	10	85
70– 80	3	88
80– 90	4	92
90–100	7	99

There appears to be an accumulation of roots between 20 and 30 cm. The rooting density rapidly decreases at depths exceeding 70 cm. As these figures represent the total weights, and the bulk of the roots at depths greater than 20 cm are primary and secondary roots, they do not give a true indication regarding the actual root surface taking part in the uptake of water and nutrients. The total dry weight of the rooting system of adult oil palms to a depth of 1 m amounts to approximately 20 tons per hectare.

5.2.7. The results obtained by WRIGHT (1951), FREMOND and ORGIAS (1952), PREVOT and OLLAGNIER (1953) and ourselves suggest that the African oil palm is a surface feeder. The growing points of the roots directly emerging from the trunk base only represent a negligible fraction of the total absorbing root surface, and are not likely to play an important part in the uptake of water and nutrients. Surface application of fertilizers is therefore indicated, but the horizontal differences in the density of the feeding roots are not sufficiently pronounced to justify band application. To reduce competition from the cover crop, however, applications on the regularily weeded area around the palm base with a slightly higher density of feeding roots would seem to give the greatest chance that the palms benefit from the fertilizers.

5.2.8. Very little is known so far concerning the relationship between soil conditions and the response of oil palms to fertilizers, although it may safely be assumed that this relationship exists. BROESHART (1955) found an almost linear relationship between the total potassium content of the top soil and the production of poor areas in the Basongo Territory. It may be expected, however, that the combined results of fertilizer experiments, soil analysis and foliar analysis in the various oil-palm-growing regions will provide the necessary basis for a sound fertilizer policy in the near future. Foliar analysis is likely to play an important part in this development, because it gives a more direct picture of the nutrient requirements of the crop than soil analysis. The results of the latter only provide an indication of part of the nutrients available for the crop, because an important part is released from the decaying vegetation that covered the area prior to the establishment of the plantation.

5.3. NUTRIENT DEFICIENCIES

5.3.1. Contrary to HOMES' experience (1949) the symptoms of a number of nutrient deficiencies of the African oil palm are rather conspicious. The absence of similar typical symptoms in his experiments is not surprising, however, in view of the fact that none of the nine solutions tested was highly deficient in one nutrient at the time. On the other hand it should be borne in mind that external symptoms resembling those caused by the deficiency of a certain nutrient do not necessarily indicate that deficiency of this nutrient is the primary cause. Other conditions, including pests and diseases, cultural malpractices, deficiencies or excesses of other nutrients, etc. may have prohibited the uptake.

5.3.2. The external symptoms of nitrogen deficiency are a general yellowing of the whole plant, beginning with the youngest leaves. As the leaves become older the colour tends to become somewhat greener. The number of leaves produced per unit of time decreases and they become shorter and smaller. Eventually, the growth ceases and the palm dies. These symptoms are known from a pot experiment (BROESHART, 1955) with six months old healthy nursery plants transplanted in quartz sand. Omission of nitrogen from the nutrient solution produced the first symptoms within two months after planting.

In practice nitrogen deficiency is not frequently encountered. Occasionally oversized seedlings in sandbeds, and nursery plants show the above type of yellowing, and moderate symptoms may be exhibited by young palms after planting out in the field. In adult palms some cases of Plant Failure exhibit a similar type of yellowing, but it seems unlikely that nitrogen deficiency is the primary cause.

Certain positive responses to applications of nitrogen fertilizers are relatively rare. This is not surprising, bearing in mind that the total supply of nitrogen in the soil is very large in comparison to the quantity immobilized in the fallow vegetation (BARTHOLOMEW *et al.*, 1953). In the Serdang replanting experiment (MALAYA, 1952) the height of the young palms one year after planting was significantly increased by nitrogen. SCHEIDECKER and PREVOT (1954) are of the opinion that young palms at Pobé (Dahomey) respond to nitrogen applications. Similar results are reported from an experiment with young palms near Benin, Nigeria (WAIFOR, 1953). Responses of producing palms to applications of nitrogen fertilizers have been obtained in experiments at Pobé, Dahomey and La Dibamba, Cameroon (IRHO, 1953) and on a coastal clay soil in Malaya (MALAYA, 1954). FERRAND (1947) states that applications of nitrogen were required to improve the health and the productivity of the palms on the sandy and heavy clay soils in Sumatra, which had become degraded as a consequence of continuous clean weeding. OPSOMER (1932), however, reports that nitrogen deficiency appears to be little in evidence in Sumatra. Excess of nitrogen seems to increase the incidence of Crown Disease.

It would, therefore, appear that nitrogen deficiency is not an important factor in oil palm cultivation.

According to the French investigators (IRHO, 1953) the critical level for nitrogen in the leaflets is 2.75 per cent on dry matter.

5.3.3. The external symptoms of phosphorus deficiency are not very conspicious, but the extreme symptoms are still unknown. Omission of phosphorus from the nutrient solution had little effect on the development of six month old healthy nursery plants transplanted in quartz sand during the first six months after planting (BROESHART, 1955). In field experiments (Elis 3, Brab 49) the colour of the leaves on the plots without phosphorus is a rather dark and dull green, with a tendency to premature desiccation of the lower whorls.

Although the total supply of phosphorus in the soil is usually large in comparison to the quantities immobilized in the crop (BARTHOLOMEW *et al.* 1953), and the removal of phosphorus by the oil palm is rather small (tables 36 and 37), positive responses to applications of phosphorus fertilizers have been obtained in a number of cases. FERRAND (1947) and OPSOMER (1932) state that phosphorus deficiency is very general in Sumatra. From the results of the pre-war Malayan manurial experiments it may be concluded (BUNTING, 1932; BELGRAVE, 1932; BELGRAVE and LAMBOURNE, 1933; BELGRAVE, 1935; BELGRAVE and LAMBOURNE, 1937; DENNETT, 1938; WILSHAW, 1940) that adult producing palms respond to applications of phosphorus fertilizers with an after-effect of at least 18 months on quartzite hill soils, but only on areas yielding not more than 1500 lb. of oil per acre. For young palms applications of nitrogen and phosphorus are economic. Rockphosphate had the same effect as basic slag. In one experiment (Estate A) the second treatment remained without effect. This was not the case in the Serdang experiment (5D), but a general reduction of the yields on all the plots was equally evident, suggesting that other deficiencies are involved. From the post-war fertilizer experiments no results are available so far.

The benefits of applications of phosphorus fertilizers is being studied in a large number of experiments in French West- and Central Africa (IRHO; 1951, 1952, 1953; FERRAND and OLLAGNIER, 1950; FERRAND, OLLAGNIER and BOYE, 1952; RANCOULE and OLLAGNIER, 1952; SCHEIDECKER and PREVOT, 1954). None of the experiments, both on young and adult palms, has revealed so far that applications of phosphorus fertilizers, usually rockphosphate, are beneficial for these regions. The same holds true for the manurial experiments including phosphorus as a treatment in Nigeria (WAIFOR, 1953). In these experiments superphosphate is being used.

In the Belgian Congo the experiments by the INEAC including phosphorus as a treatment (fertiphos and rockphosphate) equally failed to show positive responses to applications of phosphorus fertilizers. The design of the new INEAC experiments does not allow for the evaluation of the response to phosphorus to be made (VANDERWEYEN, 1952).

The easiest explanation for the absence of responses to applications of phosphorus fertilizers in Africa is the assumption that the availability of this nutrient in the soil is sufficiently high in the majority of cases to meet the requirements of the oil palm. For French Africa phosphorus fixation is not likely to have prevented responses as rockphosphate is being used. The same holds true for the INEAC-experiments in the Belgian Congo using rockphosphate and fertiphos. In Nigeria, however, superphosphate is being used, and here phosphorus fixation may play a rôle. The doses applied and the methods of application are not very different from those in Malaya and Sumatra, so that it seems highly improbable that the absence of responses is due to insufficient doses or faulty application.

Still we are of the opinion that the above explanation is not very satisfactory, in view of the fact that highly significant responses to applications of rockphosphate have been recorded in two of our experiments, one on adult producing palms at Yaligimba and one on a young replanting (Elis 3). Both experiments are established on soils having a high phosphorus fixation capacity. We wonder, therefore, whether the absence of responses to phosphorus in French West- and Central Africa and in Nigeria is not due in some cases to the prevailance of other nutrient deficiencies. It is interesting to note that the P-content of the leaves in the control plots of our above mentioned experiments is higher than the critical level suggested by the IRHO in 1952 (0.15 per cent P on dry matter), and higher than the P-content of the leaves in all the French experiments.

5.3.4. The term bronzing has been used by a number of investigators to indicate a discoloration of the leaves, which was believed to be related to potassium deficiency. In three of the Elmina progenies at Serdang, exhibiting different degrees of bronzing, it was found (MALAYA, 1952) that the degree of bronzing is inversely related to the K-content, directly related to the Ca-content, and independant of the Mg- and P-content of the leaflets. Similar observations were made by HALE (1947), who has shown that the K-content of leaves sampled from diseased palms at Nkwele (Nigeria) was lower than that of healthy palms. In the absence of coloured illustrations it is not sure that the Malayan and the Nigerian authors have referred to the same condition, but is is somewhat difficult to believe that they would have used this term to indicate symptoms similar to those described and illustrated recently by BULL (1954a & b) under the name Confluent Orange Spotting. The latter are common throughout the Nigerian oil palm belt, but little in evidence in the Belgian Congo, although isolated palms exhibiting these symptoms are present everywhere. Young and adult palms responding to applications of potassium in the Basongo Territory (BROESHART, 1954a) are not characterized by a high incidence of Confluent Orange Spotting. The almost linear relation between the K-content of the leaves and the production shown by BROESHART (1954a) for a plantation in this region does not correspond with a similar relation between the K-content and the incidence of this disease. We are, therefore, of the opinion that Confluent Orange Spotting is not a typical symptom of potassium deficiency.

THOMPSON (1941) reported that young palms grown in nutrient solutions without potassium soon develop a yellowing, accompanied by brown scorch of the tips of the pinnae. In a sand culture experiment by BROESHART (1955) omission of potassium from the nutrient solution caused a premature desiccation of the older leaves. In one of our fertilizer experiments (Brab 49) the lower leaves of some of the palms in the plots with a complete fertilizing except potassium were of a rather dark bronze-green colour, and in some cases the leaflets developed an irregular yellow margin, which subsequently desiccates and falls of. These symptoms are very similar to those described by HALE (1947) as 'general bronzing'. HALE states: "In the more general type of bronzing the tips and edges of leaflets on the lower leaves acquire an orange-yellow colour and subsequently die in much the same way as in the marginal scorch commonly associated with potassium deficiency in many other crops". Similar symptoms can be noticed in areas considered as slightly deficient in potassium, as indicated by leaf analysis and the potassium content of the soil. When seen from a distance, the most striking features in the appearance of these palms are the dark bronze-green colour of the leaves, the marginal scorch and the premature desiccation of the lower whorls. In more severe cases of potassium deficiency, as indicated by the same criteria, the whole leaflet may become yellow, but without exhibiting the conspicious orange of magnesium deficiency (5.3.5).

In Sumatra and Malaya the benefits of applications of potassium fertilizers are not general and less certain (FERRAND 1947; OPSOMER 1932; DENNETT 1938), although striking responses have been obtained in some cases (CHAPMAN & GRAY 1949). Very striking responses, both with young and adult palms, have been obtained in French West- and Central Africa (FERRAND & OLLAGNIER 1950; RANCOULE & OLLAGNIER 1952; FERRAND, OLLAGNIER & BROYE 1952; SCHEIDECKER & PREVOT 1954; IRHO 1951, 1952 & 1953), Nigeria (WAIFOR 1953) and the Belgian Congo (BROESHART 1954a), usually corresponding with an increase of the K-content of the leaves and a decrease of the Ca-content. According to the French investigators the critical level of the K-content in the leaves amounts to 1.00–1.10 per cent (on dry matter), whilst CHAPMAN & GRAY (1949) state that a K_2O/P_2O_5-ratio under 2.5 (on ash) indicates potassium deficiency.

LUC (1954) has recently drawn the attention to the experience that the incidence of Leaf Bend is increased by fertilizing with potassium. The symptoms of this disease are a downward bending of fronds, usually with a fruit bunch in the axil, until the tip is resting on the ground. The bending occurs from the point where the leaf is attached to the trunk. The cause may be purely mechanical through the greater weight of the fronds, but it is also possible that fertilizing with potassium has induced a still unknown deficiency. Although this disease is known both in the Far East and in Africa, it is little in evidence until present, and seems not to affect the production.

5.3.5. THOMPSON (1941) found that young palms growing in a nutrient solution without magnesium soon develop chlorosis and browning, resulting in their premature death. In one of our fertilizer experiments (Brab 49) the leaves of the palms on the plots with complete fertilizing except magnesium exhibit a discolouration of the distal leaflets, beginning with the older fronds. The youngest affected leaflets show a khaki colour in the interveinal regions. The tips become brown, as if they had been scorched, and the whole leaflet then develops a general conspicious orange yellow colour, which looks a bright orange when seen in mass on the palm. The orange yellow becomes scorched from the tip back, and finally the whole leaflet desiccates and the lamina may fall away. The leaves of the lower whorls are frequently completely dried out. Very similar symptoms were exhibited by six-month-old healthy nursery palms grown in sand cultures with addition of nutrient solutions without magnesium (BROESHART 1955). They are, therefore, to be considered as being typical of extreme magnesium deficiency.

We have been able to verify on the spot that BULL's description and illustration of Orange Frond disease (1954a & b) refer to the same symptoms. His injection trials have shown that the symptoms may be suppressed by leaflet-tip injections of solutions containing magnesium and by spraying affected leaves with a 2 per cent magnesium chloride solution. Moreover healthy leaf tissue contains approximately twice as much magnesium as diseased. It is concluded that Orange Frond disease is caused by magnesium deficiency, and this conclusion is supported by the results of a fertilizer experiment, in which soil application of 10 lb. magnesium sulphate to affected palms has cured the disease in nine months. No increases in yields have yet appeared, however.

From BACHY's description of a disease termed Boyomi (1949) it is highly probable that he refers to the same symptoms. This is further supported by the results of a fertilizer experiment at Etoumbi (FERRAND, BACHY & OLLAGNIER 1951, IRHO 1953) showing that the health of the palms improved after applications of magnesium sulphate in particular. The Mg-content of the leaves on the plots with magnesium was 0.153 per cent in 1953 as compared to 0.121 per cent on the control plots and 0.113 on the plots receiving a fertilizing including nitrogen, phosphorus and potassium only. According to the French investigators the critical level for magnesium is in the vicinity of 0.240 per cent (on dry matter).

Positive responses to applications of magnesium fertilizers in terms of yield have been obtained in the above experiment at Etoumbi (IRHO 1953). HARTLEY (1950) obtained positive responses to applications of Patentkali within 16 months after the application, both in number of bunches and average bunch weight, and a reduction of the symptoms of discolouration and premature desiccation of the leaves.

5.3.6. The symptoms of calcium deficiency of the oil palm are still unknown. THOMPSON's (1941) young palms growing in nutrient solutions without calcium developed normally, and the palms on the plots without calcium in our experiment (Brab 49) are perfectly healthy to date. In BROESHART's (1955) sand cultures omission of calcium in the nutrient solution has not hindered the growth. This would seem to suggest that the oil palm has moderate calcium requirements. It should be borne in mind, however, that none of the existing experiments on adult palms includes comparisons between the absolute absence of calcium in the fertilizers applied and its presence. The low Ca-content of the leaves of chlorotic palms at Sibiti (IRHO 1953) might indicate calcium deficiency. Positive responses to applications of calcium fertilizers in terms of yield are unknown so far.

5.3.7. Omission of the trace elements copper, manganese, boron, zinc and iron from the nutrient solution was without effect on the development of young seedling palms in THOMPSON's experiments (1941). In one of our fertilizer experiments, however, omission of boron from the fertilizers applied to the palms of a five years old replanting (Brab 49), caused an almost general outbreak of Little Leaf (FERWERDA 1954a & b). This suggested that boron deficiency is the cause of this disease in the majority of cases in the Belgian Congo.

Little Leaf is probably the most serious disease of young palms in the Kwango and Kasai Districts of the Belgian Congo, causing temporary or permanent improductivity, and very often death. KOVACHICH (1952) has made a comprehensive study of the external and internal symptoms of the disease, its distribution and spread. His investigations justified the conclusion, contrary to other opinions (GHESQUIERE 1935, INEAC 1948), that the disease is not primarily caused by insects or micro-organisms, but that it is either of physiological or virus origin. The outbreak of Little Leaf in the felled and fertilized areas of our replanting experiment Brab 1 (4.3.4) provided KOVACHICH (1953) with the evidence that Little Leaf is a physiological disease, probably caused by a nutrient deficiency or unbalance.

According to KOVACHICH (1952) the earliest external symptom of Little Leaf is the abnormal habit of the innermost whorl of opened leaves. These are shorter and more erect than the corresponding leaves of a healthy palm, and may be slightly chlorosed. The young unopened leaves of the central spear are free from any rotting in this stage, but later a dark brown rotting of the unopened pinnae may be observed, followed by the collapse of the central spear at a point within the central frond cylinder. The progress of the disease depends on the severity of the attack. The apical meristem may be destroyed and result in the death of the palm, or the rot may be arrested before reaching the meristem by the formation of callus tissue in the leaf rachids. In the latter case growth of the young leaves may be resumed almost immediately or, growth may be arrested for a considerable time. The first leaves to open after the rotting of the central spear are of the Little Leaf type, i.e. they are smaller than normal and distorted. The distortion of the first leaves to open may be of a mechanical type due to the necrosis of some of the pinnae and the rachids as a result of the leaves being involved in the rot. Subsequent leaves are usually untouched by the rot, but are extremely small and malformed. The malformation normally consists of the pinnae being corrugated or completely lacking. Occasionally the leaf rachids are also distorted. Succeeding leaves are usually less malformed and approximate more to healthy leaves, and eventually the palm becomes indistinguisable from a healthy palm. Palms which have apparently recovered frequently suffer from more attacks, which are commonly of a more serious nature. Occasionally Little Leaf type of leaves appear on palms without the central spears being previously rotted. Photographic pictures of the external and internal symptoms of the disease are given in KOVACHICH's publications (1951, 1952). Palms suffering from Little Leaf have abnormal arrested or rotted roots, but this condition exists before the appearance of the symptoms in the frond (KOVACHICH 1951). BACHY (1954) equally arrives at the conclusion that Little Leaf is a physiological disease, without being able to indicate the cause.

No certain data are available yet to prove that palms already suffering from Little Leaf can actually be cured by means of applications of borax, although the first results of our trials seem to indicate that this is the case, both by means of surface applications and foliar sprays. Even a palm in a very advanced stage of Bud Rot resumed growth after treatment with borax. Significant positive responses to applications of borax in terms of yield have been obtained in one case. On the other hand it has been shown that borax is toxic for palms in the first year after planting when applied in doses exceeding 10 g per palm, whilst adult palms suffer no ill effects from applications as high as 100 g.

5.3.8. Positive responses to applications of coppersulphate were obtained at La Mé, Côte d'Ivoire (IRHO 1953). Copper increased the height of nursery plants. An interesting experiment designed to study the benefits of applications of trace elements is in course at Etoumbi, Moyen Congo (FERRAND, BACHY & OLLAGNIER 1951), comparing the effect of nitrogen + phosphorus + potassium with the effects of nitrogen + phosphorus + potassium + one of the following elements: zinc, copper, iron, magnesium, manganese, boron. The experimental area has a high incidence of palms affected by Boyomi (5.3.5). The results obtained to date are rather surprising in so far that, with the exception of iron, all these elements had a favourable effect on production and disease incidence in the second and third year after the application, after due allowance had been made for the effects of initial differences between the plots by means of covariance analysis. In the fifth year (IRHO 1953) only the effect of magnesium proved to be persistent as far as yield and improvement of the health of the palms are concerned. It is interesting to note that, with the exception of zinc, all the elements have improved the phosphorus content of the leaves.

5.4. VEGETATIVE DEVELOPMENT

5.4.1. The design of our replanting experiments Elis 3 & 4 and Brab 49 enables a study of the influence of each of the nutrients nitrogen, phosphorus, potassium, magnesium, calcium, copper, manganese, boron, zinc, cobalt, nickel and molybdenum on the vegetative development of young palms to be made. Some preliminary information concerning the nutrient status of the experimental areas was available from pilot trials with maize as an indicator crop. These pilot trials, two for each area, were of the 2^n-factorial type. The results are summarized in table 42. From this it appears that phosphorus and nitrogen have improved the production of green matter in Elis 1, and phosphorus, nitrogen, potassium and minor elements in Elis 2. The experimental area of Elis 3 & 4 is in the vicinity of that of Elis 1, however.

Potassium, calcium and nitrogen have improved the green matter production in Brab 43a, potassium, calcium and phosphorus in Brab 43b. The experimental area of Brab 49 is closest to that of Brab 43b.

TABLE 42. INFLUENCE OF VARIOUS NUTRIENTS ON THE GREEN MATTER PRODUCTION OF MAIZE, 10 WEEKS AFTER PLANTING. MAIN EFFECTS AND TWO-FACTOR INTERACTIONS EXPRESSED AS A PERCENT OF THE GENERAL MEANS

	Bolembo area		Brabanta area	
	Elis 1	Elis 2	Brab 43a	Brab 43b
Main effects:				
Nitrogen (N)	24.0	15.0	13.4	5.2
Phosphorus (P)	49.4	57.1	2.6	7.9
Potassium (K)	3.6	11.7	42.9	29.1
Magnesium (Mg)	- 0.3	- 1.1	- 1.3	5.6
Calcium (Ca)	0.4	4.3	18.0	14.7
Trace el. (te) [1]	3.7	5.6	–	–
Interactions:				
N × P	8.0	13.0	6.2	- 1.1
N × K	12.2	2.2	10.3	9.5
N × Mg	- 3.5	0.8	- 2.6	-16.6
N × Ca	- 7.8	- 3.4	- 9.2	- 5.4
N × te	3.4	- 5.8	–	–
P × K	0.8	4.4	12.0	4.2
P × Mg	- 3.6	- 1.4	- 3.2	- 5.4
P × Ca	0.0	- 4.2	2.6	- 3.4
P × te	- 3.3	9.6	–	–
K × Mg	7.2	2.4	2.2	0.7
K × Ca	2.3	3.2	- 6.2	2.8
K × te	- 6.6	- 9.9	–	–
Mg × Ca	- 1.0	- 8.0	- 3.5	- 3.9
Mg × te	- 5.9	- 6.8	–	–
Ca × te	0.0	- 0.8	–	–
Sign. effect P = 0.05	5.1	5.4	9.0	7.9

[1]) Trace elements including Cu, B, Co, Ni, Zn and Mb

Although it is à priori far from certain that oil palms will react in a similar way, the results of the pilot trials seem to suggest that the soils of the Bolembo area (Elis 3 & 4) are deficient in phosphorus. This is further confirmed by the results of soil analysis (Appendix), indicating a low total P-content and a high phosphorus fixation. The soils of the Kanangai area (Brab 49) are mainly deficient in potassium according to the pilot trials. The K-content of these soils is very low, and the same holds true for the P-content, but there is no P-fixation.

5.4.2. The vegetative development of the young palms in our replanting experiment Elis 3 was followed up by counting the number of new leaves produced and by measuring the length of the youngest fully developed leaf at intervals of six months. The results of these observations are available for the period April 1952–October 1953, and shown in table 43.

As appears from the table, none of the treatments has a clear influence on the number of leaves and the length of the youngest fully opened leaf. The only significant effect is the interaction between nitrogen and phosphorus for the length of the leaves in October 1953, but in the absence of positive main effects it is advisable not to lay too much stress on this. It would, therefore appear, that nitrogen and phosphorus have no influence on the vegetative development of young oil palms on this type of soil.

TABLE 43. ELIS 3. AVERAGE NUMBER OF LEAVES PRODUCED PER PERIOD OF SIX MONTH AND AVERAGE LENGTH OF THE YOUNGEST FULLY DEVELOPED LEAF AT THE END OF THESE PERIODS

Factor	Number of leaves			Length of leaves		
	X/52	IV/53	X/53	X 52	IV/53	X/53
N_0P_0	9.8	11.3	14.1	188	242	321
N_1P_0	10.4	11.5	14.9	188	247	335
N_2P_0	9.9	11.5	14.4	197	253	339
N_0P_1	9.7	13.3	14.2	187	241	328
N_1P_1	10.4	11.4	14.4	187	243	323
N_2P_1	11.0	11.9	14.6	170	265	354
N_0P_2	10.4	11.9	14.7	187	246	345
N_1P_2	11.2	11.9	15.2	192	257	342
N_2P_2	10.4	11.6	14.6	178	236	311
$\overline{N}_0$	10.0	12.2	14.3	187	243	331
$\overline{N}_1$	10.7	11.6	14.8	189	249	333
$\overline{N}_2$	10.4	11.7	14.5	182	251	335
$\overline{P}_0$	10.0	11.4	14.5	191	247	332
$\overline{P}_1$	10.4	12.2	14.3	181	250	335
$\overline{P}_2$	10.7	11.8	14.8	185	246	333
$\overline{NP}$	10.4	11.8	14.5	186	248	333

5.4.3. A similar series of observations is available for our replanting experiment Elis 4. The results are shown in table 44.

Here again none of the nutrients tested has significantly affected the number of leaves or the length of the youngest fully developed leaf. The only effect approaching significance is the negative response to applications of potassium in the length of the leaves at the end of the last period. This would seem to indicate that potassium, magnesium, calcium, copper, manganese, boron and trace elements (zinc, nickel, cobalt and molybdenum) have no influence on the vegetative development of young palms on this type of soil during the third and fourth year after planting.

5.4.4. A corresponding series of observations is available for the length of the youngest fully developed leaf in the replanting experiment Brab 49. It should be borne in mind, when considering these figures, that the palms in this experiment grew under the canopy of part of the old stand for a period of nearly five years, approximately 25 per cent being removed prior to replanting. The results of these measurements are shown in table 45. From this it appears that the differences were small, but never-

TABLE 44. ELIS 4. AVERAGE NUMBER OF LEAVES PRODUCED PER PERIOD OF SIX MONTHS, AND AVERAGE LENGTH OF THE YOUNGEST FULLY DEVELOPED LEAF AT THE END OF THESE PERIODS

	Number of leaves			Length of leaves		
	X/52	IV/53	X/53	X/52	IV/53	X/53
+ K	10.8	11.2	14.2	197	262	339
- K	11.5	11.8	14.9	219	269	367
+ Mg	11.3	11.7	14.8	212	278	358
- Mg	11.0	11.3	14.4	205	253	349
+ Ca	10.9	11.5	14.5	206	270	350
- Ca	11.4	11.5	14.7	210	261	356
+ Cu	11.3	11.6	14.4	212	274	360
- Cu	11.0	11.4	14.7	204	256	346
+ Mn	11.2	11.4	14.6	208	266	353
- Mn	11.0	11.6	14.6	208	265	354
+ B	11.0	11.4	14.1	203	264	348
- B	11.3	11.6	15.1	213	267	358
+ te [1])	11.2	11.6	14.7	209	273	355
- te	11.1	11.4	14.5	207	258	351

[1]) Trace elements (Zn + Ni + Co + Mb)

TABLE 45. BRAB 49. LENGTH OF THE YOUNGEST FULLY DEVELOPED LEAF

	XII/'53	XI/'54
1) Complete fertilizing (N + P + K + Mg + Ca + Cu + Mn + B + Zn + Ni + Co + Mb)	284	367
2) As 1) without nitrogen (N)	280	362
3) As 1) without phosphorus (P)	272	354
4) As 1) without potassium (K)	269	336
5) As 1) without magnesium (Mg)	280	363
6) As 1) without calcium (Ca)	307	399
7) As 1) without copper (Cu)	308	387
8) As 1) without manganese (Mn)	290	371
9) As 1) without boron (B)	284	355
10) As 1) without zinc (Zn)	281	366
11) As 1) without nickel (Ni)	303	405
12) As 1) without cobalt (Co)	278	371
13) As 1) without molybdenum (Mb)	282	371
14) Control (no fertilizing)	249	321
General average	283	366
Significant difference (P = 0.05)	27	29

theless significant between the control plots and all the other treatments with a length equal to or exceeding 276 cm in December 1953, 10 months after the first fertilizer applications. If potassium and phosphorus were omitted from the fertilizing, however, the latter did not significantly increase the length of the youngest leaf as compared to the control. None of the treatments is significantly better than complete fertilizing at this stage, apart from the control. In November 1954, 21 months after the first fertilizer application, the differences between the various treatments had considerably increased. The plots receiving a complete fertilizing and all the other plots, except those receiving a complete fertilizing with omission of potassium, were better as far as the length of the youngest fully developed leaf is concerned than the control plots.

It is interesting to note, however, that one of the treatments, omission of potassium, is significantly worse than complete fertilizing, suggesting that potassium deficiency affects the length of the leaves. Omission of phosphorus and boron have the same effect, but the difference does not reach the level of significance. A number of treatments (omission of calcium and omission of nickel) are significantly better than complete fertilizing, and omission of nitrogen, magnesium, copper, manganese, zinc cobalt and molybdenum have little or no effect on the length of the leaves. This suggests that calcium and nickel tend to decrease the length of the leaves on this type of soil.

5.4.5. The results of our experiments indicate that potassium is the only nutrient affecting the length of the leaves for the conditions studied, the influence of phosphorus and boron not being certain. Excess of potassium may equally cause a decrease in the length, suggesting that there exists an optimum supply of potassium as far as the length of the leaves is concerned. The significant negative responses to calcium and nickel suggest that excess of these nutrients is harmful to the vegetative development on the Kanangai soils. The same probably holds true for copper. The supply of these nutrients in the Kanangai soils seems to be sufficient to assure a normal development, as far as the length of the leaves is concerned. The same is probably true for nitrogen, magnesium, zinc, cobalt and molybdenum. None of the nutrients studied seems to affect the leaf production and the length of the leaves on the Bolembo soils, suggesting that their supply is sufficient to assure a normal vegetative development during the first three or four years after planting.

5.5. Disease incidence and mortality

5.5.1. Until October 1953, 42 months after planting, the incidence of diseases and the percentage of missing palms in Elis 3 was practically nil, and not related to the treatments applied. From a total of 972 palms planted only 11 were missing in October 1953. A disease census made in October 1954 has revealed, however, that a number of palms is suffering from Little Leaf disease. The results of this census are shown in table 46. To avoid decimal places the incidence of Little Leaf disease is given as the number of diseased palms per treatment combination (108 palms) and per single treatment (324 palms). From the analysis of variance of these data it appeared that the only treatment variance being significantly greater than the error variance is that for phosphorus ($F = 3.92$, $n_1 = 2$, $n_2 = 16$). It may, therefore, be concluded that the incidence of Little Leaf disease on the plots without phosphate is lower than that on the plots with the lowest phosphate dressing, and that on the latter lower than that on the plots with the highest phosphate dressing. The results further suggest that, although these differences are not significant as a consequence of the high experimental error in comparison with the average incidence of the disease, the incidence of Little Leaf is also increased by nitrogen, and that the interaction between nitrogen and phosphorus is positive in this respect. Confirmatory evidence is required, however, to support this indication.

It should be borne in mind that no boron has been applied in this experiment until October 1954.

TABLE 46. ELIS 3. INCIDENCE OF LITTLE LEAF DISEASE PER TREATMENT COMBINATION (108 PALMS) AND PER SINGLE TREATMENT (324 PALMS)

Factor	Number
N_0P_0	1
N_1P_0	1
N_2P_0	2
N_0P_1	3
N_1P_1	10
N_2P_1	5
N_0P_2	5
N_1P_2	13
N_2P_2	11
$\overline{N}_0$	9
$\overline{N}_1$	24
$\overline{N}_2$	18
$\overline{P}_0$	4
$\overline{P}_1$	18
$\overline{P}_2$	29
S.D. 5%	2

5.5.2. The disease incidence in Elis 4 until October 1953 (nearly four years after planting) was equally negligible, although the mortality was slightly higher. From a total of 560 palms planted 17 were missing in October 1953. As was the case in Elis 3, the disease census of October 1954 revealed that a number of palms is now suffering from Little Leaf. The results of this census are shown in table 47. The incidence of Little Leaf disease is given as the number of diseased palms per single treatment (280 palms). The analysis of variance of these data has shown that only the variance for boron is significantly greater than the error variance ($F = 7{,}46$, $n_1 = 1$, $n_2 = 8$). From this it appears that the incidence of Little Leaf disease on the plots with boron is significantly lower than that on the plots without boron. None of the other treatment differences is significant, although those for potassium and trace elements are very nearly so. It is interesting to note that the differences in incidence of Little Leaf for the other treatments only refer to the plots without boron, the plots

TABLE 47. ELIS 4. INCIDENCE OF LITTLE LEAF DISEASE PER SINGLE TREATMENT (280 PALMS)

Factor	Number	S.D. 5%
+ K	18	
− K	5	
+ Mg	14	
− Mg	9	
+ Ca	14	
− Ca	9	
+ Cu	12	
− Cu	11	
+ Mn	12	
− Mn	11	
+ B	0	3
− B	23	
+ te	4	
− te	19	

with boron being completely free from the disease to date. They have, therefore, more the caracter of an interaction than of a main effect, or, in other terms, the other nutrients only affect the incidence of Little Leaf disease in the absence of sufficient boron. This is illustrated in table 48. It would, therefore, appear that the incidence of Little Leaf in the absence of sufficient boron is increased by potassium, magnesium and calcium, not affected by copper and manganese, and reduced by trace elements (zinc + nickel + cobalt + molybdenum).

TABLE 48. ELIS 4. INCIDENCE OF LITTLE LEAF DISEASE PER TWO-FACTOR TREATMENT COMBINATION (140 PALMS)

	K		Mg		Ca		Cu		Mn		te	
	+	−	+	−	+	−	+	−	+	−	+	−
+ B	0	0	0	0	0	0	0	0	0	0	0	0
− B	18	5	14	9	14	9	12	11	12	11	4	19

5.5.3. The corresponding series of obervations for Brab 49 are summarized in table 49. Here the effect of fertilizing became already evident 10 months after the first applications so far as the disease incidence is concerned, illustrating the poor nutrient status of the Kanangai soils as compared with those of Bolembo. The diseases observed include Little Leaf, Wilt, Orange Frond and Plant Failure. Two cases of Patch Yellow and one case of an unspecified root rot are omitted from the table. The treatment variance for all the tabulated diseases is significantly greater than the error variance, except that for Plant Failure. As the cause of the death of the missing palms in this experiment is known, the latter are included in the diseases and not separately tabulated. In the majority of cases the palms died as a consequence of Wilt. The total number of missing palms amounted to 7 in December 1953 and to 26 in November 1954 (from 896 palms).

TABLE 49. BRAB 49. DISEASE INCIDENCE PER TREATMENT (64 PALMS)

Factor	Healthy		Little Leaf		'Wilt'		Orange Frond		Plant Failure	
	'53	'54	'53	'54	'53	'54	'53	'54	'53	'54
1) Complete fertilizing	59	54	1	–	4	9	–	–	–	1
2) As 1) without N	55	54	2	–	5	10	–	–	–	–
3) As 1) without P	52	39	1	2	10	18	1	1	–	4
4) As 1) without K	45	40	1	–	17	14	1	3	–	7
5) As 1) without Mg	9	18	1	–	2	7	53	38	–	1
6) As 1) without Ca	60	53	1	4	3	4	3	2	–	–
7) As 1) without Cu	60	49	–	–	4	10	–	1	–	4
8) As 1) without Mn	58	54	–	–	6	7	–	–	–	3
9) As 1) without B	9	23	53	35	2	6	–	–	–	–
10) As 1) without Zn	55	49	2	2	7	10	–	1	–	2
11) As 1) without Ni	62	56	–	1	1	5	1	–	–	2
12) As 1) without Co	58	54	1	2	4	7	1	–	–	1
13) As 1) without Mb	52	49	2	–	7	3	3	9	–	2
14) No fertilizing	20	39	2	1	24	7	17	15	–	2
Sign. diff. ($P = 0.05$)	3	3	9	9	6	6	8	8	–	–

5.5.4. The number of healthy palms is greatly improved by fertilizing, but only phosphorus, potassium, magnesium and boron, and to a lesser extent copper, zinc and molybdenum seem to be essential on this type of soil. The improvement of the health of the palms by potassium, phosphorus and boron corresponds with an increase in the length of the leaves (5.4.4), but although omission of magnesium did not affect the length of the leaves, it greatly reduced the number of healthy palms.

5.5.5. The incidence of Little Leaf is very different between the plots, and practically limited to the plots with a complete fertilizing without boron. This provided the necessary evidence to prove that Little Leaf disease is caused by boron deficiency in the majority of cases (FERWERDA 1954a). The isolated cases of Little Leaf in the other plots may have different origins, including insects, fungi and mechanical damage. It should be borne in mind that KOVACHICH (1952) succeeded in reproducing the rotting of the young leaves by cutting the roots. Moreover the quantities of borax applied may be insufficient to prevent Little Leaf in all cases. It may seem somewhat surprising that only one or two cases of Little Leaf are found in the control plots. The probable explanation is that the control plots, although equally deficient in boron, are still more deficient in one or more additional nutrients. The latter may have limited the growth to such an extent that boron deficiency does not occur.

5.5.6. For the palms tabulated as 'Wilt' it should be stressed that this only refers to external symptoms, viz. a premature desiccation of the older leaves without the additional symptoms of yellowing immediately prior to this desiccation. They are certainly not a sharply defined group as is the case for the palms affected by Little

Leaf or, to a lesser extent, Orange Frond. Some cases approach those usually termed as Plant Failures (WARDLAW 1946 ref. BULL 1954). In the first census no distinction was made between Plant Failure and Wilt, and therefore our comparison must be based on the total of 'Wilt' and Plant Failure.

It appears that only the omission of phosphorus and potassium have increased the incidence of Wilt and Plant Failure as compared to the plots with complete fertilizing. The control plots had a high incidence of these diseases at the time of the first census, but were not significantly different from the completely fertilized plots when the second census was carried out. None of the other treatments is significantly different from the completely fertilized plots so far as the incidence of Wilt and Plant Failure is concerned, although some amount of these diseases is present in all the plots. This would seem to suggest that some 10 per cent of all the palms planted is affected by Vascular Wilt caused by *Fusarium oxysporum* (WARDLAW 1950), independent of the treatments, and frequently causing their premature death. The high incidence of Wilt in the control plots in the beginning is probably the after-effect of shading by the old stand. A similar decrease could be noted in the non-felled, non-fertilized areas of Brab 1 after removal of the old stand (table 19). Omission of phosphorus and potassium is not likely to increase the incidence of *Fusarium* Wilt, although the susceptibility of the palms to this disease may be increased. A more probable explanation would appear to be that the higher incidence of Wilt in the plots without phosphorus or potassium as compared to those with a fertilizing including these nutrients are straight symptoms of phosphorus- and potassium deficiency. A number of palms in the plots without potassium exhibit the additional symptoms mentioned earlier (5.3.4), but they are not yet sufficiently numerous to justify a separate classification.

5.5.7. The palms exhibiting the symptoms termed as Orange Frond (5.3.5) were almost exclusively found in the plots receiving a complete fertilizing with omission of magnesium and the control plots. The obvious conclusion is that Orange Frond is caused by magnesium deficiency, and that magnesium is the major nutrient lacking in the Kanangai soil after removal of the old stand. Similar symptoms were shown by the young palms in the felled areas of Brab 1 (4.3.5) immediately after removal of the old stand.

The isolated cases of Orange Frond disease in the plots belonging to the other treatments are probably genetic in origin, with the possible exception of part of those in the plots with a complete fertilizing without molybdenum. Another possibility is that the level of application of magnesium was too low. This will be demonstrated by the development of the yellowing in these plots in the future.

5.6. CHEMICAL COMPOSITION

5.6.1. The influence of applications of various nutrients on the chemical composition of the leaves of palms in areas replanted after complete removal of the old stand, prior to replanting, was followed up in our replanting experiments Elis 3 and Elis 4. Elis 3 was sampled twice for foliar analysis, the first time 18 months after the first fertilizer applications (42 months after planting), the second time 12 months later. For Elis 4 the results of one sampling, 18 months after the first applications (nearly four years after planting) are available.

5.6.2. The phosphorus content of the leaves found in the two samplings of Elis 3 is shown in table 50. From this it may be noted that the increase in the phosphorus content is almost proportional to the level of application of rockphosphate, both after 18 and 30 months. This would seem to suggest that the phosphorus content is still below the optimum, especially because the level of application was considerably increased after the first sampling (5 and 10 kg of rockphosphate per palm as compared to 900 and 1800 g prior to the first sampling). Nitrogen seems to have little effect, if any, on the phosphorus content, although there is an indication of a decrease with increasing level of application of nitrochalk at the highest level of application of rockphosphate in the second sampling. The interaction between phosphorus and nitrogen seems to be negative as far as the phosphorus content of the leaves is concerned, the increase of the latter being greater in the absence than in the presence of nitrogen fertilizers.

TABLE 50. ELIS 3. PHOSPHORUS CONTENT OF THE FIRST FULLY OPENED LEAF, 18 AND 30 MONTHS AFTER THE FIRST APPLICATION OF FERTILIZERS (42 AND 54 MONTHS AFTER PLANTING). PERCENTAGES ON DRY MATTER AND ON ASH

	Per cent on dry matter		Per cent on ash	
	X/'53	X/'54	X/'53	X/'54
N_0P_0	0.182	0.197	3.08	2.31
N_0P_1	0.198	0.214	2.87	2.59
N_0P_2	0.213	0.272	3.69	3.15
N_1P_0	0.188	0.222	2.96	2.67
N_1P_1	0.201	0.236	3.68	2.67
N_1P_2	0.258	0.255	4.24	2.98
N_2P_0	0.181	0.209	2.70	2.30
N_2P_1	0.194	0.236	2.79	2.61
N_2P_2	0.216	0.237	4.06	2.68
$\bar{N}_0$	0.198	0.228	3.20	2.68
$\bar{N}_1$	0.216	0.238	3.62	2.76
$\bar{N}_2$	0.197	0.227	3.18	2.53
$\bar{P}_0$	0.184	0.209	2.91	2.42
$\bar{P}_1$	0.198	0.229	3.10	2.60
$\bar{P}_2$	0.229	0.255	3.99	2.93
Sign. diff. [1]) $P = 0.05$	0.027	0.024	0.64	0.37

[1]) Single treatment means only

The corresponding series of data for Elis 4 is shown in table 51. From this it appears that the phosphorus content of the leaf is not affected by the presence or absence of potassium, magnesium, calcium, copper, manganese, boron and trace elements (zinc, nickel, cobalt and molybdenum) in the fertilizers applied on the Bolembo soils. This would seem to suggest that the uptake of phosphorus was not limited by the deficiency of one of the above nutrients in the fourth year after planting.

It is interesting to compare these data with those for the replanting experiments Brab 1 and Yal 12. In both experiments the phosphorus content is of the same order as that for Elis 3 & 4, suggesting that it is equally below the optimum.

TABLE 51. ELIS 4. CHEMICAL COMPOSITION OF THE FIRST FULLY OPENED LEAF, 18 MONTHS AFTER THE FIRST FERTILIZER APPLICATIONS (4 YEARS AFTER PLANTING). PERCENTAGES PHOSPHORUS, POTASSIUM, MAGNESIUM, CALCIUM AND ASH ON DRY MATTER

	% P	% K	% Mg	% Ca	% ash
+ K	0.191	2.23	0.377	0.620	7.32
- K	0.186	2.00	0.381	0.654	6.79
+ Mg	0.186	2.00	0.380	0.619	7.07
- Mg	0.191	2.23	0.380	0.654	7.05
+ Ca	0.183	1.91	0.373	0.659	6.87
- Ca	0.194	2.31	0.385	0.616	7.24
+ Cu	0.183	2.08	0.388	0.609	7.24
- Cu	0.194	2.15	0.371	0.665	6.87
+ Mn	0.184	2.17	0.371	0.663	6.49
- Mn	0.193	2.06	0.387	0.611	7.62
+ B	0.194	2.12	0.370	0.612	7.22
- B	0.183	2.11	0.388	0.661	6.90
+ te	0.193	2.16	0.416	0.654	7.47
- te	0.184	2.07	0.342	0.620	6.64

5.6.3. The potassium content of the leaves (table 52) shows neither a clear relationship with the nitrogen nor with the phosphorus dressing in Elis 3. The general level of leaf-potassium is high in an absolute sense. The corresponding data for Elis 4 (table 51) indicate that the potassium content is slightly increased by applications of this nutrient, but decreased by applications of both calcium and magnesium, although the general level is high. As the potassium content seems to be near to its maximum (4.4.4), it is unlikely that the uptake of this nutrient is limited by magnesium or calcium deficiency in the soil. The probable explanation is that the high potassium content must be considered as an additional symptom of phosphorus deficiency, as the phosphorus content of the leaves is known to be negatively proportional to the potassium content (CHAPMAN & GRAY 1949, BROESHART 1954a).

The corresponding data for the replanting experiments Brab 1 and Yal 12 (4.4.4) indicate a somewhat lower level, which may be considerably increased by means of fertilizing in the case of Brab 1. In the case of Yal 12 a slight increase could be noted, corresponding with an increase in leaf phosphorus. This would seem to suggest that the uptake of potassium on the Kanangai soil is mainly limited by potassium deficiency, whilst on the Yaligimba soil both potassium and phosphorus are deficient.

5.6.4. The magnesium content of the leaves in Elis 3 shows no clear trend (table 53),

TABLE 52. ELIS 3. POTASSIUM CONTENT OF THE FIRST FULLY OPENED LEAF, 18 AND 30 MONTHS AFTER THE FIRST APPLICATION OF FERTILIZERS (42 AND 54 MONTHS AFTER PLANTING). PERCENTAGES ON DRY MATTER AND ON ASH

	Per cent on dry matter		Per cent on ash	
	X/'53	X/'54	X/'53	X/'54
N_0P_0	1.86	2.73	31.5	31.9
N_0P_1	1.91	2.93	27.3	34.9
N_0P_2	1.95	2.49	33.3	28.7
N_1P_0	1.93	2.72	30.8	32.9
N_1P_1	1.52	2.76	27.6	31.1
N_1P_2	2.18	2.76	36.2	32.1
N_2P_0	1.94	2.88	29.1	31.5
N_2P_1	1.89	3.06	27.0	34.0
N_2P_2	1.67	2.62	31.1	29.1
$\bar{N}_0$	1.90	2.72	30.7	31.9
$\bar{N}_1$	1.88	2.75	31.5	32.1
$\bar{N}_2$	1.83	2.85	29.0	31.5
$\bar{P}_0$	1.91	2.78	30.4	32.1
$\bar{P}_1$	1.77	2.92	27.3	33.4
$\bar{P}_2$	1.93	2.62	33.5	30.0

TABLE 53. ELIS 3. MAGNESIUM CONTENT OF THE FIRST FULLY OPENED LEAF, 18 AND 30 MONTHS AFTER THE FIRST APPLICATION OF FERTILIZERS (42 AND 54 MONTHS AFTER PLANTING). PERCENTAGES ON DRY MATTER AND ON ASH

	Per cent on dry matter		Per cent on ash	
	X/'53	X/'54	X/'53	X/'54
N_0P_0	0.440	0.278	7.39	3.25
N_0P_1	0.386	0.379	5.55	4.56
N_0P_2	0.388	0.270	6.66	3.13
N_1P_0	0.388	0.355	6.07	4.31
N_1P_1	0.356	0.293	6.45	3.27
N_1P_2	0.364	0.354	5.89	4.14
N_2P_0	0.365	0.326	5.48	3.61
N_2P_1	0.339	0.286	4.83	3.16
N_2P_2	0.381	0.225	7.02	2.39
$\bar{N}_0$	0.405	0.309	6.53	3.64
$\bar{N}_1$	0.369	0.334	6.14	3.91
$\bar{N}_2$	0.362	0.379	5.77	3.09
$\bar{P}_0$	0.387	0.320	6.31	3.72
$\bar{P}_1$	0.360	0.319	5.61	3.66
$\bar{P}_2$	0.378	0.283	6.52	3.25

although the differences are considerable, both when expressed on a dry matter and on an ash basis. The corresponding data for Elis 4 (table 51) indicate that only the application of a mixture of the trace elements zinc, nickel, cobalt and molybdenum causes a considerable increase of the magnesium content. The general level is higher than the critical value of 0.240 (on dry matter) suggested by the IRHO (1953), and in the region of BROESHART's optimal values (1954a). This would seem to indicate that the uptake of magnesium is not limited by magnesium deficiency in the Bolembo soils.

The corresponding data for Kanangai are equally in the optimal region, but those for Yaligimba are considerably lower and even below the critical value of the French.

5.6.5. The calcium content of the leaves in Elis 3 is not affected by the applications of nitrogen and phosphorus (table 54). In Elis 4 the calcium content is decreased by applications of potassium, magnesium, copper and boron, but increased by calcium, manganese and trace elements. The corresponding data for Brab 1 are considerably higher for the non-felled, non-fertilized areas before the removal of the old stand. The calcium content for Yal 12 was rather high.

TABLE 54. ELIS 3. CALCIUM CONTENT OF THE FIRST FULLY OPENED LEAF, 18 AND 30 MONTHS AFTER THE FIRST APPLICATION OF FERTILIZERS (42 AND 54 MONTHS AFTER PLANTING). PERCENTAGES ON DRY MATTER AND ON ASH

	Per cent on dry matter		Per cent on ash	
	X/'53	X/'54	X/'53	X/'54
N_0P_0	0.531	0.521	8.97	6.09
N_0P_1	0.548	0.430	7.87	5.19
N_0P_2	0.506	0.480	8.71	5.53
N_1P_0	0.564	0.524	9.15	6.36
N_1P_1	0.538	0.531	9.82	6.01
N_1P_2	0.561	0.591	9.48	6.91
N_2P_0	0.524	0.488	7.86	5.31
N_2P_1	0.546	0.496	7.77	5.50
N_2P_2	0.612	0.628	11.45	7.06
$\overline{N}_0$	0.528	0.477	8.52	5.60
$\overline{N}_1$	0.554	0.549	9.49	6.43
$\overline{N}_2$	0.561	0.538	9.03	5.96
$\overline{P}_0$	0.540	0.511	8.66	5.92
$\overline{P}_1$	0.544	0.486	8.49	5.57
$\overline{P}_2$	0.560	0.567	9.88	6.50

5.6.6. BROESHART (1955) found that the chemical composition of the leaves of palms having regional maximum growth and/or production fluctuates within rather narrow limits, suggesting that there is an optimal composition for oil palm leaves. According to the French investigators (IRHO 1952) an element is likely to be deficient if its content in the leaves falls below a critical level. These and BROESHART's norms are summarized in table 55.

TABLE 55. OPTIMAL LEAF COMPOSITION (BROESHART) AND CRITICAL LEVELS (IRHO)

	BROESHART		IRHO
	Dry matter	Ash	Dry matter
Phosphorus (P)	0.21–0.23	3.0– 3.5	0.15
Potassium (K)	1.7 –1.9	25 –28	1.00
Magnesium (Mg)	0.25–0.35	3.7– 4.8	0.24
Calcium (Ca)	0.55–0.66	7 – 9	0.60

BROESHART (1955) found further, when studying the changes in leaf composition of young palms growing in quartz sand, and watered daily with a complete nutrient solution or a nutrient solution in which nitrogen, phosphorus, potassium, calcium or magnesium was omitted, the deviations from the optimal composition (= complete nutrient solution) shown in table 56.

TABLE 56. CHANGES IN LEAF COMPOSITION IN COMPARISON TO THE NORMAL COMPOSITION THROUGH NUTRIENT DEFICIENCIES

Nutrient deficiency	Potassium		Phosphorus		Magnesium		Calcium	
	dr. m.	ash	dr. m.	ash	dr. m.	ash	dr. m.	ash
Nitrogen, early	0	–	+	0	+	+	+	0
do. , late	0	–	0	0	0	–	0	0
Phosphorus, early	0	0	–	–	0	0	–	–
do. , late	0	0	–	0	–	0	0	0
Potassium, early	–	–	0	+	+	+	+	+
do. , late	–	–	+	+	–	–	+	+
Magnesium, early	0	0	0	0	–	–	+	0
do. , late	0	0	0	0	–	–	+	0
Calcium, early	0	0	–	–	+	0	–	–
do. , late	0	0	–	–	–	0	–	–

0 = normal composition; + = higher than normal; – = lower than normal

From this it appears that, although deficiency of phosphorus, potassium, magnesium or calcium in the nutrient solution always corresponds with a low content of these nutrients on a dry matter basis, a low content of a nutrient in the dry matter does not necessarily means that that particular nutrient is deficient in the growing medium. In the following table we have applied these principles to the foliar analysis data from our replanting experiments, and indicated, where possible, which nutrient is likely to be deficient (table 57). From this it appears that it is generally impossible, with few exceptions, to conclude the deficiency of one single nutrient when using BROESHART's criteria. This is not surprising in view of the fact that the method only permits the diagnosis of the absolute deficiency of nitrogen, phosphorus, potassium, magnesium or calcium so far, and illustrates its greater precision in comparison with the IRHO-criteria. With increasing knowledge concerning the influence of two or more nutrients simultaneously deficient to a greater or lesser extent, and the influence of deficiencies of other nutrients, it seems likely that it will become possible to explain the major part of the positive or negative deviations from an 'optimal' chemical composition. A point deserving close attention in this respect is in our opinion the influence of excesses of one or more nutrients, as the latter obtain in practice, even on poor soils under tropical conditions. It is common experience that young palms in the first year after planting exhibit more or less severe symptoms of Orange Frond disease, which usually disappear in the course of the second year. It is interesting to note that the results of foliar analysis of the felled areas in Brab 1 (a, 1951) and of the completely felled areas in Yal 12 (3/3, 1954) suggest magnesium deficiency.

TABLE 57. DIAGNOSIS OF NUTRIENT DEFICIENCIES IN THE REPLANTING EXPERIMENTS WITH THE AID OF BROESHART'S AND THE IRHO-CRITERIA

Exp.	Tr.	Year	Dry matter				Ash				Criteria	
			P	K	Mg	Ca	P	K	Mg	Ca	BROESHART	IRHO
Brab 1	(i)	1951	.	.	.	.	+	–	0	+	K, Mg?	
do.	do.	1953	.	.	.	.	+	0	–	+	Mg, K?	
do.	(a)	1951	.	.	.	.	+	+	–	0	Mg	
do.	(a)	1953	.	.	.	.	+	0	0	0	?	
do.	(b)	1951	.	.	.	.	+	+	+	0	?	
do.	(b)	1953	.	.	.	.	+	0	–	0	Mg	
do	(ab)	1951	.	.	.	.	0	+	0	–	Ca?, P?	
do.	(ab)	1953	.	.	.	.	0	0	0	0	P?	
Yal 12	3/3	1954	0	0	–	0	0	0	–	+	Mg	Mg
do.	2/3	do.	0	–	–	+	0	–	–	+	K?	Mg
do.	1/3	do.	0	–	–	+	0	–	–	+	K?	Mg
do.	0/3	do.	+	–	–	+	0	–	–	+	K	Mg
do.	Fert.	do.	+	–	–	+	0	–	–	+	K	Mg
do.	No fert.	do.	0	–	–	+	0	–	–	+	K?	Mg
Elis 3	$\bar{N}_0$	1953	–	0	+	–	0	+	+	0	Ca	Ca
do.	$\bar{N}_0$	1954	0	+	0	–	–	+	–	–	P?, Ca?	Ca
do.	$\bar{N}_1$	1953	0	0	+	0	+	+	+	+	?	Ca
do.	$\bar{N}_1$	1954	+	+	0	0	–	+	0	–	Ca?, P?	Ca
do.	$\bar{N}_2$	1953	–	0	+	0	0	+	+	0	P?	Ca
do.	$\bar{N}_2$	1954	0	+	+	–	–	+	–	–	?	Ca
do.	$\bar{P}_0$	1953	–	0	+	–	–	+	+	0	Ca?	Ca
do.	$\bar{P}_0$	1954	0	+	0	–	–	+	0	–	Ca?, P?	Ca
do.	$\bar{P}_1$	1953	–	0	+	–	0	0	+	0	Ca?, P?	Ca
do.	$\bar{P}_1$	1954	0	+	0	–	–	+	0	–	P?, Ca?	Ca
do.	$\bar{P}_2$	1953	0	0	+	0	+	+	+	+	?	Ca
do.	$\bar{P}_2$	1954	+	+	0	0	–	+	–	–	?	Ca
Elis 4	+ K	1953	–	+	+	0	.	.	.	.	?	?
do.	– K	do.	–	+	+	0	.	.	.	.	?	?
do.	+ Mg	do.	–	+	+	0	.	.	.	.	?	?
do.	– Mg	do.	–	+	+	0	.	.	.	.	?	?
do.	+ Ca	do.	–	0	+	+	.	.	.	.	?	?
do.	– Ca	do.	–	+	+	0	.	.	.	.	?	?
do.	+ Cu	do.	–	+	+	0	.	.	.	.	?	?
do.	– Cu	do.	–	+	+	+	.	.	.	.	?	?
do.	+ Mn	do.	–	+	+	+	.	.	.	.	?	?
do.	– Mn	do.	–	+	+	0	.	.	.	.	?	?
do.	+ B	do.	–	+	+	0	.	.	.	.	?	?
do.	– B	do.	–	+	+	+	.	.	.	.	?	?
do.	+ te	do.	–	+	+	0	.	.	.	.	?	?
do.	– te	do.	–	+	+	0	.	.	.	.	?	?

Ref. tables 24–31, 50–56

5.7. MALE AND FEMALE INFLORESCENCES AND BUNCHES

5.7.1. Observations on the number of male inflorescences and female inflorescences and fruit bunches present in the crown are available for Elis 3 & 4 and Brab 49, so that the influence of applications of a great number of nutrients in replanted areas on the early production may be followed on two very different soil types.

5.7.2. Table 58 gives a summary of the number of male inflorescences, the number of female inflorescences and fruit bunches per palm, and the percentage of producing palms for Brab 49. From this it appears that complete fertilizing and complete fertilizing with omission of all the other nutrients except potassium and magnesium have increased the number of male inflorescences in 1953 over and above the control. Omission of copper and possibly omission of boron, moreover, have increased the number of male inflorescences over and above complete fertilizing, whilst omission of the other nutrients has no significant effect. In 1954 only complete fertilizing and complete fertilizing minus nitrogen, magnesium, copper, manganese and nickel have caused an increase over and above the control, whilst the plots with a complete fertilizing minus phosphorus and boron have produced less male inflorescences than complete fertilizing, and the plots minus copper more. This would seem to suggest that potassium and magnesium play an important part in the course of the first year after removal of the old stand, and phosphorus and boron and possibly zinc and cobalt in the course of the second year on the Kanangai soil.

TABLE 58. BRAB 49. NUMBER OF MALE INFLORESCENCES, NUMBER OF FEMALE INFLORESCENCES, PERCENTAGE OF PRODUCING PALMS

Factor	Male inflorescences		Female inflorescences & fruit bunches		Prod. palms %
	XII. 53	XI. 54	XII. 53	XI. 54	XI 54
1) Compl. fert.	0.83	0.39	0.31	2.98	44
2) As 1) – N	0.76	0.40	0.40	2.95	51
3) As 1) – P	0.70	0.23	0.61	2.79	52
4) As 1) – K	0.52	0.32	0.40	2.28	41
5) As 1) – Mg	0.41	0.38	0.09	2.24	41
6) As 1) – Ca	0.86	0.32	0.33	2.97	56
7) As 1) – Cu	1.13	0.56	0.53	2.74	44
8) As 1) – Mn	0.75	0.46	0.52	3.38	54
9) As 1) – B	1.06	0.23	0.12	2.41	57
10) As 1) – Zn	0.66	0.29	0.10	2.68	46
11) As 1) – Ni	0.70	0.42	0.38	3.21	58
12) As 1) – Co	0.74	0.28	0.42	3.25	56
13) As 1) – Mb	0.68	0.32	0.27	3.22	57
14) Control	0.30	0.24	0.13	0.44	11
General average	0.72	0.35	0.33	2.68	48
Sign. diff. P = 0.05 . . .	0.30	0.15	0.18	0.56	6

5.7.3. The number of female inflorescences and fruit bunches (table 58) is already significantly higher than that on the control plots in 1953 for the completely fertilized plots and those receiving a complete fertilizing minus all the other nutrients except magnesium, boron and zinc. The latter plots are also significantly lower than the completely fertilized plots, whilst the plots receiving a complete fertilizing minus phosphorus, copper and manganese and maybe cobalt are higher. From this it may be concluded that magnesium, boron and zinc are important factors for the early production of replanted palms on this type of soil in the course of the first year after removal of the old stand. In 1954 the number of female inflorescences and fruit bunches on all the fertilized plots was significantly higher than that on the control plots, and that on the plots receiving a complete fertilizing minus potassium, magnesium, boron and possibly zinc lower than complete fertilizing. This suggests that potassium, magnesium and boron, and possibly zinc are important for the production in the second year after removal of the old stand.

5.7.4. The percentage of producing palms is greatly increased by fertilizing (table 58), but this is probably only due to one or more of the nutrients potassium, magnesium, copper and zinc, as omission of the other nutrients results in an increase of this percentage over and above complete fertilizing. Omission of boron, however, is known to induce Little Leaf disease.

5.7.5. The number of male inflorescences present in the crown after various periods of time for Elis 3 is shown in table 59. From this it appears that there is a positive response to phosphorus at the higher level and to nitrogen at both levels of application in October 1953. The largest response was obtained with nitrogen at the lower and phosphorus at the higher level. The differences in the previous counts do not reach the level of significance at P = 0.05. This would seem to indicate that nitrogen and phosphorus affect the number of male inflorescences present 42 months after planting and 18 months after the first application of these fertilizers.

TABLE 59. ELIS 3. NUMBER OF MALE INFLORESCENCES, NUMBER OF FEMALE INFLORESCENCES AND FRUIT BUNCHES, PERCENTAGE OF PRODUCING PALMS

Factor	Male infloresc.			Female inflorescences and fruit bunches				Producing palms per cent			
	X. 52	IV. 53	X. 53	X. 52	IV. 53	X. 53	X. 54	X. 52	IV. 53	X. 53	X. 54
N_0P_0	2.9	5.9	8.0	0.1	0.8	5.0	5.6	6	13	53	71
N_0P_1	2.2	5.2	6.5	0.1	0.4	6.1	7.4	4	6	57	73
N_0P_2	2.9	6.5	8.1	0.3	1.0	8.2	9.6	5	17	68	87
N_1P_0	2.5	5.8	8.6	0.1	0.7	5.4	6.6	3	10	53	72
N_1P_1	2.0	5.9	9.1	0.4	0.9	5.9	6.0	7	14	49	76
N_1P_2	2.6	6.0	10.0	0.1	0.7	7.4	8.3	3	23	69	87
N_2P_0	2.7	5.1	7.3	0.5	0.8	5.6	6.6	10	16	52	64
N_2P_1	3.1	7.2	9.1	0.2	1.0	7.3	7.4	4	14	73	81
N_2P_2	1.8	6.4	9.8	0.0	0.5	4.3	7.1	2	10	56	67
$\bar{N}_0$	2.7	5.8	7.5	0.2	0.7	6.4	7.5	5	12	59	77
$\bar{N}_1$	2.4	5.9	9.2	0.2	0.8	6.2	7.0	4	16	57	78
$\bar{N}_2$	2.6	6.2	8.8	0.3	0.8	5.7	7.0	5	13	60	70
$\bar{P}_0$	2.7	5.6	8.0	0.3	0.8	5.3	6.2	6	13	52	69
$\bar{P}_1$	2.4	6.1	8.2	0.3	0.8	6.4	6.9	5	12	60	77
$\bar{P}_2$	2.4	6.3	9.3	0.2	0.8	6.6	8.3	3	17	64	80
$\overline{NP}$	2.5	6.0	8.5	0.2	0.8	6.1	7.2	5	14	59	77
S.D.	n.s.	n.s.	1.3	n.s.	n.s.	n.s.	1.3	n.s.	n.s.	6	10

$\overline{NP}$ = general average; S.D. = significant difference P = 0.05; n.s. = non significant

5.7.6. In the number of female inflorescences and fruit bunches (table 59) positive responses to phosphorus were obtained at both levels of application in October 1953 and 1954, but negative responses to nitrogen. Phosphorus seems to act best in the absence of, or at the lower level of nitrogen. None of the responses in 1953, however, reach significance at the 5 per cent level of probability. This may seem surprising in view of their magnitude, but it should be borne in mind that only a limited number of the palms had produced female inflorescences at this stage, and that this number showed large fluctuations from plot to plot, independent of the treatment.

5.7.7. The percentage of producing palms shows equally positive responses to applications of phosphorus, although to a lesser extent than the average number of female inflorescences and fruit bunches per palm, but is independent from the level of application of nitrogen. The differences are only significant since October 1953. This would seem to suggest that at least part of the responses to phosphorus recorded to date mean earlier rather than higher production at this stage. The relationship between the percentage of producing palms per plot and the average number of female inflorescences and fruit bunches in October 1953 is shown in a dot diagram, including also the corresponding data for Elis 4 (figure 8). The significance of this relationship was

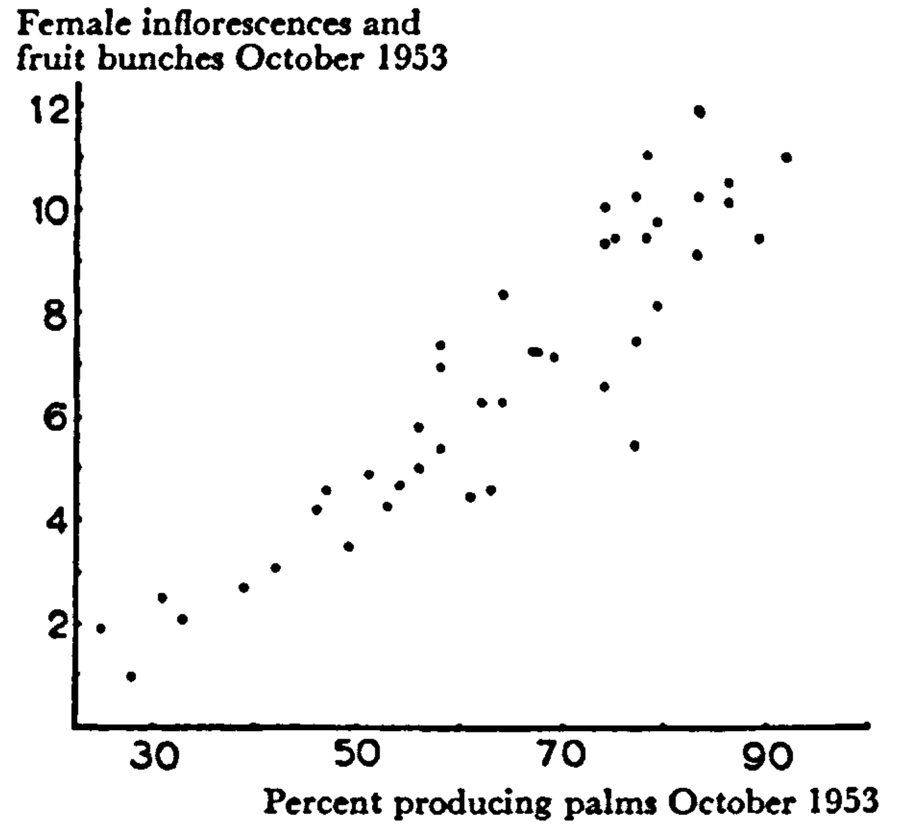

FIG. 8. ELIS 3 & 4. RELATIONSHIP BETWEEN THE AVERAGE NUMBER OF FEMALE INFLORESCENCES AND FRUIT BUNCHES PER PALM AND THE PERCENTAGE OF PRODUCING PALMS IN OCTOBER 1953

analysed for the last series of data from Elis 3 (October 1954). The analysis is shown in table 60. From this may be derived that the regression coefficient of the number of

TABLE 60. ELIS 3, 1954. ANALYSIS OF VARIANCE AND COVARIANCE FOR THE NUMBER OF FEMALE INFLORESCENCES AND FRUIT BUNCHES (X) AND THE PERCENTAGE OF PRODUCING PALMS (Y)

	Degrees of freedom	Sum of squares		Sum of products
		x	y	xy
Total	26	65.70	3,708	336.3
Blocks	2	5.31	859	67.4
Treatments	8	34.91	1,609	171.7
Error	16	25.48	1,240	97.2
Nitrogen (N)	2	1.61	327	7.5
Phosphorus (P) . . .	2	19.74	577	98.7
N × P	4	13.56	705	65.5

female inflorescences and fruit bunches on the percentage of producing palms amounts to 0.07838, and that its variance is significantly greater ($P = 0.05$) than the sum of squares of the deviations from this regression ($F = 6.40$ for $n_1 = 1$, $n_2 = 15$). The analysis of reduced variance may now be validly applied to adjust the data for the number of female inflorescences and fruit bunches for the variation in the percentage of producing palms. This analysis yields reduced variances of 3.12 for P and 1.13 for N, which are not significantly greater than the reduced error variance (1.19). Consequently it is still uncertain whether the increase of the number of female inflorescences through applications of rockphosphate is due to higher or to earlier production, although the former seems more probable in view of the magnitude of the responses.

5.7.8. The number of male inflorescences for Elis 4 (table 61) shows positive responses to applications of minor elements in October 1953, and negative responses to potassium in October 1952 and April 1953. This would seem to indicate that there was still an excess of potassium in the soil at the time of the first applications of fertilizers (April 1952), but that one or more of the trace elements zinc, nickel, cobalt and molybdenum were in short supply towards October 1953 (4 years after planting and removal of the old stand).

TABLE 61. ELIS 4. NUMBER OF MALE INFLORESCENCES AND NUMBER OF FEMALE INFLORESCENCES AND FRUIT BUNCHES PER PALM. PERCENTAGE OF PRODUCING PALMS

Factor	Male infloresc.			Female inflorescences and fruit bunches				Producing palms per cent			
	X. 25	IV. 53	X. 53	X. 52	IV. 53	X. 53	X. 54	X. 52	IV. 53	X. 53	X. 54
+ K	3.9	6.8	9.7	0.4	1.3	7.0	9.3	8	20	70	86
- K	5.5	8.8	10.3	0.5	1.9	8.8	12.0	11	28	75	90
+ Mg	4.8	8.2	10.5	0.5	1.6	8.4	10.5	9	24	76	90
- Mg	4.6	7.5	9.4	0.4	1.6	7.4	10.8	10	25	69	86
+ Ca	4.6	7.8	10.2	0.3	1.3	7.4	10.2	8	21	68	87
- Ca	4.8	7.9	9.8	0.6	1.9	8.5	11.2	11	27	76	89
+ Cu	4.8	8.0	10.4	0.5	1.7	8.6	11.4	9	26	75	89
- Cu	4.6	7.7	9.6	0.4	1.5	7.3	9.9	10	23	69	87
+ Mn	4.5	7.8	10.3	0.4	1.4	8.0	10.2	8	24	74	89
- Mn	5.0	7.8	9.7	0.6	1.8	7.8	11.1	11	25	71	87
+ B	4.4	7.6	10.0	0.4	1.2	7.0	8.8	9	19	69	85
- B	5.1	8.0	10.0	0.5	2.0	8.8	12.5	10	29	75	90
+ te.	5.0	8.2	11.0	0.6	1.7	7.8	10.6	10	23	72	87
- te.	4.4	7.4	9.1	0.4	1.6	8.0	10.7	9	25	72	89
M.	4.7	7.8	10.0	0.5	1.6	7.9	10.7	9	24	72	88
S.D.	1.5	1.6	2.0	n.s.	n.s.	n.s.	3.3	n.s.	n.s.	n.s.	n.s.

M = general average; S.D. = significant difference P = 0.05; n.s. = non significant.

5.7.9. The number of female inflorescences and fruit bunches for Elis 4 (table 61) shows a positive response to applications of magnesium and copper, and negative responses to potassium, calcium, and boron in October 1953, but none of these reached significance at the 5 per cent level of probability. In the previous period (April 1953) the same negative responses were apparent. The data for October 1954 show two clear negative responses, viz. to potassium and boron, but only that for boron is significant. Pending confirmatory evidence these data tend to suggest the presence of an excess of potassium in the soil. The negative responses to boron in terms of production, however, are probably due to the fact that boron is toxic for two-years old palms in the quantities applied (32 g borax per palm).

5.7.10. The percentage of producing palms is not significantly affected by any of the treatments in Elis 4 (table 61). This would seem to suggest that the negative response to boron is not due to a later coming into bearing, but actually to a lower production per palm. Although the variance of the regression coefficient of the number of female inflorescences and fruit bunches on the percentage of producing palms is significantly greater than the sum of squares of the deviations from this regression ($F = 10.44$ for $n_1 = 1$ and $n_2 = 7$), the analysis of reduced variance for the factor boron just fails to reach significance at the 5 per cent level of probability ($F = 4.48$ for $n_1 = 1$ and $n_2 = 7$). It is, therefore, still uncertain whether the negative response to boron is mainly due to a lower production per palm.

5.7.11. With a view to obtaining a more precise picture of the responses to the various nutrients tested in Elis 3 & 4 in terms of production of female inflorescences and fruit bunches, efforts were made to trace the possible causes of the rather large values of the standard deviations, amounting to 42 and 40 per cent respectively in October 1953. When plotting the number of female inflorescences and fruit bunches present in October 1953 against: –

i) number of leaves produced in the periods April–September 1952, October 1952–March 1953, April–September 1953;
ii) length of the youngest fully opened leaf at the end of the above periods;
iii) number of male inflorescences at the end of the above periods;

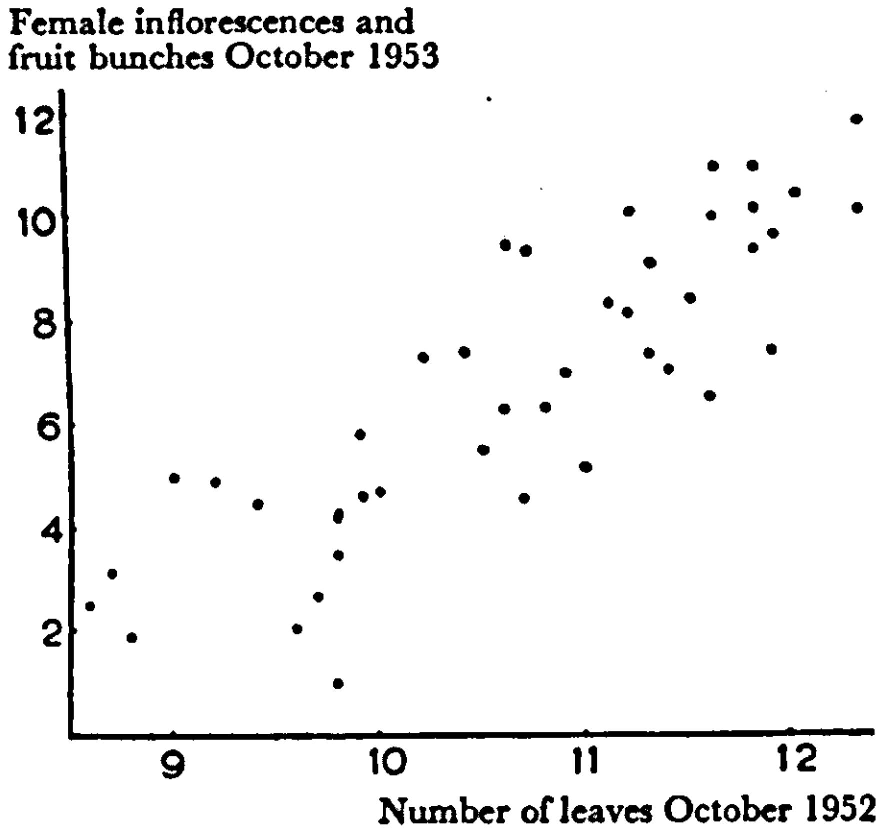

FIG. 9. ELIS 3 & 4. RELATIONSHIP BETWEEN THE AVERAGE NUMBER OF FEMALE INFLORESCENCES AND FRUIT BUNCHES PER PALM IN OCTOBER 1953 AND THE AVERAGE NUMBER OF LEAVES PRODUCED IN THE PERIOD APRIL–SEPTEMBER 1952

it appears already from a visual inspection of the dot diagrams that there is a high degree of association with some of these data. This holds especially true for the relationship between the number of female inflorescences and fruit bunches and: –

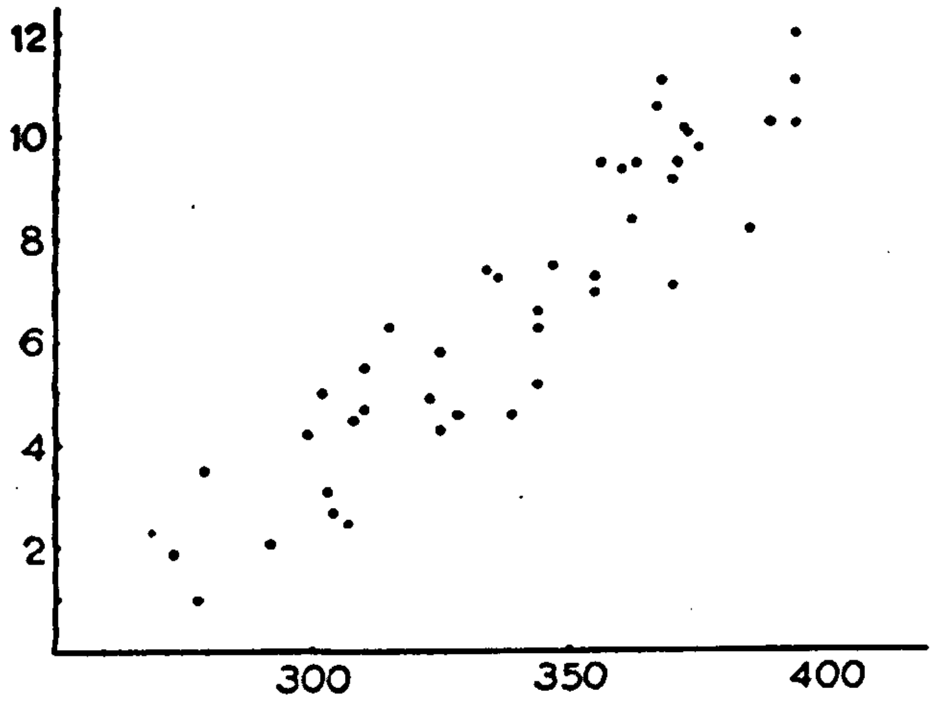

FIG. 10. ELIS 3 & 4. RELATIONSHIP BETWEEN THE AVERAGE NUMBER OF FEMALE INFLORESCENCES AND FRUIT BUNCHES PER PALM AND THE AVERAGE LENGTH OF THE YOUNGEST FULLY DEVELOPED LEAF IN OCTOBER 1953

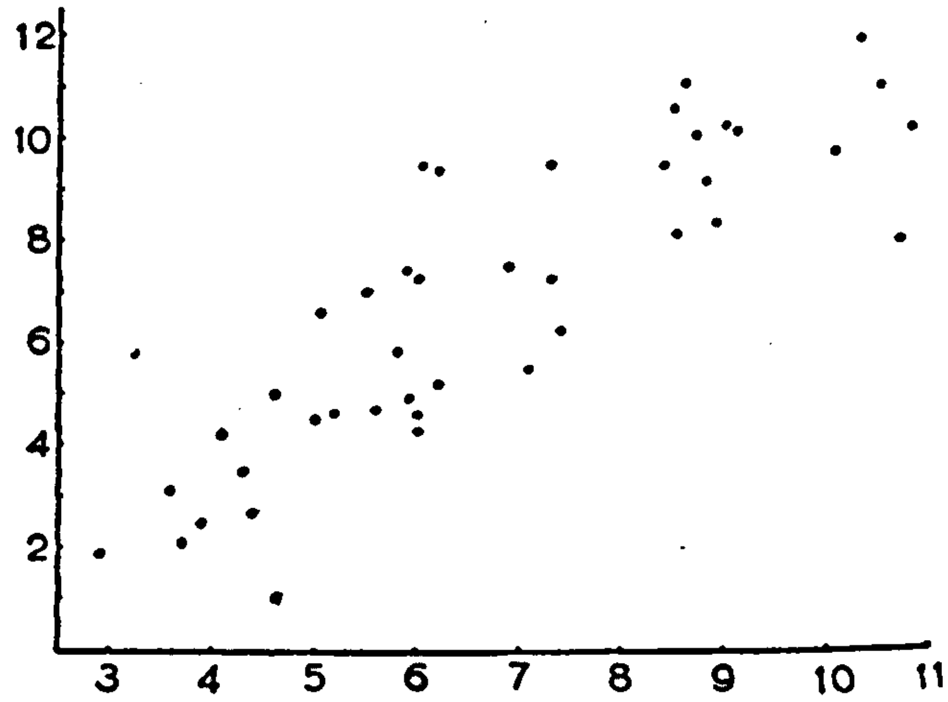

FIG. 11. ELIS 3 & 4. RELATIONSHIP BETWEEN THE AVERAGE NUMBER OF FEMALE INFLORESCENCES AND FRUIT BUNCHES IN OCTOBER 1953 AND THE AVERAGE NUMBER OF MALE INFLORESCENCES IN APRIL 1953

a) the number of leaves produced in the period April–September 1952;
b) the length of the youngest fully opened leaf at the end of each period, but especially at the end of the period April–September 1953;
c) the number of male inflorescences present at the end of the periods April-September 1952 and October 1952–March 1953.

Some of these dot diagrams are shown in the figures 9, 10 and 11.

5.7.12. The high degree of association between the number of male inflorescences in October 1952 and April 1953, and the number of female inflorescences and fruit bunches present in October 1953 does not provide a better picture of the responses, as expressed in the number of female inflorescences and fruit bunches, because the number of male inflorescences itself depends to some extent on the presence or absence of certain nutrients. It might indicate, pending confirmatory evidence, that responses in terms of yield to applications of nitrogen, phosphorus, and minor elements may be expected at some future date.

The high degree of association between the number of female inflorescences and fruit bunches present in October 1953, and both the number of leaves produced in the period April–September 1952 and the length of the youngest fully opened leaf at the end of each period of observation, suggests that a more precise picture of the responses to fertilisers, expressed in terms of production, will be obtained by eliminating the effects of number or length of leaves, as the variations in the latter are independent from the fertilizer treatments. This has been done for the effect of the length of the youngest fully opened leaf in October 1953.

5.7.13. Calculation of the ratio of the variance of the regression coefficient of the number of female inflorescences and fruit bunches on the length of the youngest fully opened leaf and the variance of the deviations from the regression for Elis 3 and Elis 4 shows that the regression coefficients are significant at the 0.1 per cent level of probability. The adjusted treatment means for the number of female inflorescences and fruit bunches may now be calculated by means of the equations: –

$x_t^! = x_t - 0.10014\ (y_t - 333.1)$ for Elis 3, and
$x_t^! = x_t - 0.06624\ (y_t - 353.2)$ for Elis 4,

where: –

$x_t^!$ = the adjusted treatment mean,
x_t = the treatment mean before adjustment,
y_t = the non-adjusted treatment mean of the length of the youngest fully opened leaf in October 1953 corresponding with the non-adjusted treatment mean of the number of female inflorescences and bunches.

The results of these calculations are shown in the tables 63 and 64. The increase in precision obtained may be estimated by calculating the ratio between the original

TABLE 62. ELIS 3 & 4. ORIGINAL, RESIDUAL AND EFFECTIVE RESIDUAL ERROR VARIANCE FOR THE DATA IN TABLE 63 AND 64

Experiment	Original	Residual	Effective residual
Elis 3	6.67	0.99	1.05
Elis 4	9.82	1.51	1.57

TABLE 63. ELIS 3. NUMBER OF FEMALE INFLORESCENCES AND FRUIT BUNCHES IN OCTOBER 1953, BEFORE AND AFTER ADJUSTMENT FOR THE VARIATION RELATED TO THE LENGTH OF THE YOUNGEST FULLY OPENED LEAF IN OCTOBER 1953

Factor	Number		% of control	
	before	after	before	after
N_0P_0	4.97	6.18	100	100
N_0P_1	6.13	6.64	123	107
N_0P_2	8.17	6.98	164	113
N_1P_0	5.40	5.24	109	85
N_1P_1	5.90	6.91	119	112
N_1P_2	7.37	6.48	148	105
N_2P_0	5.60	5.01	113	81
N_2P_1	7.33	5.21	147	84
N_2P_2	4.27	6.51	86	105
$\overline{N}_0$	6.42	6.60	100	100
$\overline{N}_1$	6.22	6.21	97	94
$\overline{N}_2$	5.73	5.57	89	84
$\overline{P}_0$	5.32	5.47	100	100
$\overline{P}_1$	6.46	6.26	121	114
$\overline{P}_2$	6.60	6.65	124	122

TABLE 64. ELIS 4. NUMBER OF FEMALE INFLORESCENCES AND FRUIT BUNCHES IN OCTOBER 1953, BEFORE AND AFTER ADJUSTMENT FOR THE VARIATION RELATED TO THE LENGTH OF THE YOUNGEST FULLY OPENED LEAF IN OCTOBER 1953

Factor	Number		% of control	
	before	after	before	after
− K	8.80	7.87	100	100
+ K	7.04	7.97	80	101
− Mg	7.44	7.74	100	100
+ Mg	8.40	8.10	113	108
− Ca	8.52	8.24	100	100
+ Ca	7.41	7.59	88	92
− Cu	7.26	7.73	100	100
+ Cu	8.58	8.12	118	105
− Mn	8.00	7.98	100	100
+ Mn	7.84	7.86	98	98
− B	8.80	8.48	100	100
+ B	7.04	7.37	80	87
− te	8.02	8.16	100	100
+ te	7.81	7.68	97	94

error variance and the effective residual error variance. The latter may be computed from the residual error variance with FINNEY's formula for the contribution of the term in y. The error variance before adjustment, the residual error variance and the effective residual variance are given below: –

From this it appears that the precision of the comparisons between treatments has been increased over six-fold. Notwithstanding this greater precision none of the adjusted treatment variances reaches significance at the 5 per cent level of probability ($P = 0.1$ for phosphorus, $P = 0.2$ for nitrogen and boron), so that the significance of the treatment differences is still somewhat uncertain.

5.7.14. The data for October 1954 were submitted to a similar analysis, although the responses to phosphorus and boron were already significant at the 5 per cent level of probability without adjustment. This time the number of leaves produced in the period April–September 1953 has been used to eliminate part of the plot to plot variance. The results of this adjustment are reproduced for Elis 3 in table 65. For Elis 4 the regression for the number of female inflorescences and fruit bunches in October 1954 on the number of leaves produced in the period April–September 1953 was non-significant. The increase in precision obtained for Elis 3 is relatively small (1.4 as compared to 6.35 in 1953) but sufficient to prove the significance of the negative interaction between nitrogen and phosphorus. The adjusted standard deviation amounts to 14.5 per cent as compared to 17 per cent before adjustment.

TABLE 65. ELIS 3. NUMBER OF FEMALE INFLORESCENCES AND FRUIT BUNCHES IN OCTOBER 1954, BEFORE AND AFTER ADJUSTMENT FOR THE VARIATION RELATED TO THE NUMBER OF LEAVES PRODUCED IN THE PERIOD APRIL-SEPTEMBER 1953

Factor	Number		Adjusted s.d. 5 %	% of control	
	before	after		before	after
N_0P_0	5.6	5.9	1.58	100	100
N_0P_1	7.4	7.7	1.65	132	131
N_0P_2	9.6	9.4		171	159
N_1P_0	6.6	6.2	1.76	118	105
N_1P_1	6.0	6.4	1.92	107	108
N_1P_2	8.3	7.6		148	129
N_2P_0	6.6	6.7	1.59	118	114
N_2P_1	7.4	7.3	1.58	132	125
N_2P_2	7.1	6.7		127	114
$\bar{N}_0$	7.5	7.7	n.s.	100	100
$\bar{N}_1$	7.0	6.8	n.s.	93	88
$\bar{N}_2$	7.0	7.0		93	91
$\bar{P}_0$	6.2	6.3	0.54	100	100
$\bar{P}_1$	6.9	7.2	0.59	111	114
$\bar{P}_2$	8.3	8.0		134	127

5.7.15. From the adjusted treatment means it may now be validly concluded that phosphorus has increased the number of female inflorescences and fruit bunches present in October 1954, but only in the absence of nitrogen. This increase amounts to 31 per cent over and above the control (no nitrogen, no phosphorus) for the first level of application and to 59 per cent for the second level. This result may seem rather surprising in view of the fact that the total amounts of phosphorus applied per palm since the beginning of the experiment are approximately 6 and 12 kg rockphosphate respectively, corresponding with some 120 and 240 kg phosphorus per ha in the present case. The removal of phosphorus by the young palms in the same period may be estimated at some 25 kg per ha, so that one would hardly expect a doubling of the response when applying 12 instead of 6 kg. This is probably due to the fact that the uptake of phosphorus from rockphosphate is only possible by direct contact of the absorbing palm roots with the surface of a rockphosphate particle on this type of soil, and it is evident that the chance of a root meeting a rockphosphate particle is doubled by doubling the level of application for the same rooting density. In the future, with increasing rooting density around rockphosphate particles, these differences are likely to level out.

5.8. CONCLUSIONS

5.8.1. The results of our experiments suggest that the benefits of applications of nitrogen fertilizers are highly uncertain for replanted areas in the Belgian Congo. This is not surprising in view of the fact that palms exhibiting the external symptoms of nitrogen deficiency are little in evidence in this country, both in replanted areas and new extensions on forest land. The only rather uncertain responses to applications of nitrogen recorded were an increase in the incidence of Little Leaf disease, a slight increase in the calcium content of the leaves and a slight increase in the average number of male inflorescences on the Bolembo soil (Elis 3).

5.8.2. The benefits of applications of phosphorus fertilizers to replanted areas are evident on a soil with a high phosphorus-fixation capacity (Bolembo) and highly probable on a soil with a low phosphorus content (Kanangai). As the external symptoms of phosphorus deficiency are not typical, leaf and soil analysis are required to provide an early basis for diagnosis. Soil analysis should include the determination of the phosphorus-fixation capacity. In the absence of similar data phosphorus deficiency may easily be overlooked, although it is almost certain to exist in many regions of the Belgian Congo.

The responses to applications of phosphorus recorded were a slight, but somewhat uncertain, increase in the length of the leaves, and improvement of the health through a decrease in the premature desiccation of the older leaves, and a somewhat uncertain increase in the number of male inflorescences on the Kanangai soil (Brab 49), and a 60 per cent increase in the number of female inflorescences and fruit bunches, corresponding with an increase in the number of male inflorescences, an increase in the phosphorus content and a slight but uncertain increase in the calcium content of the leaves, and an increase in the incidence of Little Leaf disease on the Bolembo soil (Elis 3). It is evident that the increase in the incidence of Little Leaf disease is due to induced boron deficiency, which may easily be prevented by simultaneous applications of borax or an other suitable boron fertilizer.

The critical level of leaf phosphorus as suggested by the IRHO seems too low for the conditions prevailing in the palm-growing regions of the Belgian Congo.

5.8.3. Applications of potassium fertilizers to replanted areas proved to be beneficial on a soil with a low potassium content (Kanangai), but tended to cause yield depressions on a soil with a high potassium content (Bolembo). Although the external symptoms of the palms provide some indication of potassium deficiency, they are not sufficiently reliable for a diagnosis without the additional information from foliar analysis and fertilizer experiments.

The responses to applications of potassium fertilizers in the Kanangai area (Brab 49) were a 30 per cent increase in the number of female inflorescences and fruit bunches, corresponding with an increase in the number of male inflorescences, an improvement of the general health of the palms by reducing the symptoms of premature desiccation of the older leaves, and by increasing the length of the leaves. The latter was also observed in another replanted area in the vicinity. From this experiment (BROESHART 1954a) data for leaf analysis are available, showing that applications of potassium have increased the potassium content of the leaves, but decreased the phosphorus and calcium content and to a lesser degree also the magnesium content. On the Bolembo soil (Elis 4) potassium tended to decrease the number of female inflorescences and fruit bunches, corresponding with a slight, but uncertain decrease in the number of male inflorescences, an increase of the potassium, but a decrease in the calcium content of the leaves, and an increase in the incidence of Little Leaf disease. The latter holds only true, however, if potassium was applied in the absence of boron.

The critical level for leaf potassium as suggested by the IRHO seems too low for the Belgian Congo.

5.8.4. Very striking responses to applications of magnesium fertilizers in replanted areas have been obtained on the Kanangai soil, but on the Bolembo soil the effect was practically nil. The symptoms of magnesium deficiency are very conspicuous, but easier to prevent (Brab 49) than to cure (BULL 1954), and very common in replanted areas. Slight cases very generally occur immediately after removal of the old stand, but disappear in the course of the second year. They are probably due to a temporary excess of potassium, released from the decomposing roots of the old palms, which are relatively rich in potassium and poor in magnesium and calcium. Similar symptoms are often exhibited by replacement palms, and young palms in extension areas on forest land.

In some areas, especially in the Kwango and Kasai regions, they reappear in the course of the fourth year after planting or later, sometimes preceeded by the symptoms of Little Leaf disease. These Orange Frond palms become worse and worse, although they seldom die, and eventually develop into one of the types of Plant Failure.

On the Kanangai soil (Brab 49) magnesium increased the number of female inflorescences and fruit bunches by 30 per cent, increased the number of male inflorescences, and improved the general health of the palms by practically completely suppressing the symptoms of Orange Frond disease. The length of the leaves, however, was not affected. On the Bolembo soil (Elis 4) the number of female inflorescences and fruit bunches was not so far affected by magnesium. A slight, but uncertain increase in the number of male inflorescences could be noted, together with a slight decrease in the potassium and calcium content of the leaf. Magnesium increased the incidence of Little Leaf disease on this type of soil when applied in the absence of boron.

Palms with a magnesium content in the leaves below the critical level suggested by the IRHO do not generally display the external symptoms of magnesium deficiency in the Belgian Congo.

5.8.5. The benefits of applications of calcium are highly uncertain for replanted areas in the Belgian Congo, although the pH of the soils is usually low (4.3–5.0 for our experimental areas). On the Kanangai soil calcium only reduced the length of the leaves, but did not affect the disease incidence, the number of male inflorescences and the number of female inflorescences and fruit bunches. On the Bolembo soil (Elis 4) calcium caused a slight, but uncertain decrease of the number of female inflorescences and fruit bunches, did not affect the number of male inflorescences, slightly increased the calcium and decreased the potassium content of the leaves, and increased, when applied in the absence of boron, the incidence of Little Leaf disease. It had no influence on the number and the length of the leaves.

The critical level for the calcium content in the leaves as suggested by the IRHO seems too low, as according to this criterion the palms in the Bolembo area would suffer from calcium deficiency, which is obviously not the case.

5.8.6. No certain responses to applications of copper and manganese in replanted areas have been recorded so far. Neither of these nutrients affected the vegetative growth. Copper caused a slight but somewhat uncertain improvement in the general health at Kanangai (Brab 49) by reducing the incidence of premature desiccation of the older leaves, decreased the number of male inflorescences, but did not affect the number of female inflorescences and fruit bunches. At Bolembo (Elis 4) copper caused a slight decrease in the calcium content of the leaves and slight, but uncertain increases in both the number of male inflorescences and of female inflorescences and fruit bunches.

Neither at Kanangai nor at Bolembo manganese affected the health of the palms. It caused a slight increase in the calcium content of the leaves at Bolembo, corresponding with a slight and uncertain increase in the number of male inflorescences and a slight and uncertain decrease in the number of female inflorescences and fruit bunches. At Kanangai it only affected the number of female inflorescences and fruit bunches in a negative sense.

5.8.7. The benefits of applications of boron are very evident for the Kasai and Kwango region of the Belgian Congo, but probably also for areas where Little Leaf disease is little in evidence up to the present time. The symptoms of boron deficiency are so conspicuous that they may hardly be overlooked or mistaken, but it would be unwise to defer applications of a suitable boron fertilizer till after the appearance of the first external symptoms of Little Leaf disease. Kovachich (1953) has presented evidence to suggest that the delay between the time when the palm is first affected and the opening of the first abnormal leaf is equivalent to at least the time required for the production of six leaves.

On the Kanangai soil boron increased the number of female inflorescences and fruit bunches by nearly 25 per cent, corresponding with a decrease in the number of male inflorescences, a very striking improvement in the health of the palm by almost completely preventing Little Leaf disease, and a slight but uncertain increase in the length of the leaves. At Bolembo, however, boron caused a decrease in the number of female inflorescences and fruit bunches amounting to 30 per cent, although the health of the palms was improved by entirely preventing Little Leaf disease. The calcium content of the leaves was slightly decreased in this area. These seemingly contradictory results as far as production is concerned are probably related with the rate of application, which was about twice as high at Bolembo as at Kanangai (32 g and 17 g borax per palm). In another replanted area in a region with a high incidence of Little Leaf disease the application of 20 g borax to approximately six-month-old-palms caused a discolouration beginning with the youngest leaves.

Boron deficiency is probably increased by applications of nitrogen and phosphorus, potassium, calcium, and magnesium, and decreased by one or more of the trace elements zinc, nickel, cobalt and molybdenum.

Although some evidence is available to suggest that even advanced cases of boron deficiency may be cured by means of surface applications or sprays of borax, it is almost certain that it is easier to prevent Little Leaf disease than to cure it. It is not impossible that symptoms similar to those of boron deficiency may have a different origin, including mechanical damage by insects and other as yet unknown nutrient deficiencies.

5.8.8. The rôle of zinc, nickel, cobalt and molybdenum in the nutrition of the oil palm is still very uncertain. A mixture of these elements applied on the Bolembo soil (Elis 4) decreased the incidence of Little Leaf disease on the plots without boron, increased the magnesium content and, to a lesser extent, the calcium content of the leaves, and increased the number of male inflorescences. At Kanangai (Brab 49) zinc improved the health of the palms by preventing the premature desiccation of the oldest leaves, and caused slight and uncertain increases in both the number of male inflorescences and the number of female inflorescences and fruit bunches. Cobalt only produced an uncertain increase in the number of male inflorescences and an uncertain decrease in the number of female inflorescences and fruit bunches. Nickel caused a rather conspicious decrease in the length of the leaves, and an uncertain decrease in the number of female inflorescences and fruit bunches. Molybdenum improved the health of the palms by preventing symptoms similar to those of Orange Frond disease caused by magnesium deficiency, but caused a slight, although uncertain, decrease in the number of female inflorescences and fruit bunches. These results suggest that zinc and molybdenum deficiency may obtain in certain areas.

5.8.9. The responses obtained to the single nutrients tested at Kanangai and Bolembo suggest that the first effect of fertilizing recorded in the replanting experiment discussed in the previous chapter (Brab 1) is mainly due to magnesium in the felled, and potassium and magnesium in the non-felled areas. If the fertilizers applied since 1951 had included boron, magnesium and more phosphorus it seems likely that better responses would have been obtained and Little Leaf disease would have been prevented. In the Yaligimba replanting experiment (Yal 12) the soil seems to be deficient in phosphorus, potassium and magnesium, suggesting that applications of magnesium and phosphorus are required to assure normal growth after removal of the old stand.

5.8.10. In the light of the improved knowledge concerning the nutrient deficiency symptoms of the African oil palm it becomes more and more probable that the disease complex termed Plant Failure includes the extreme symptoms of at least three different nutrient deficiencies, viz. magnesium, potassium and phosphorus. All these were already mentioned in the very comprehensive description of the disease complex by WARDLAW in 1946 (ref. BULL 1954), who was the first to use the term 'Plant Failure'. The symptoms in common are slow growth, a dwarfed, tapering trunk, a rigid, obconical disposition of the discoloured leaves and the premature desiccation of one, two or more of the semi-erect lower whorls, and a defective rooting system in the later stages. The discolouration, however, may by typical of magnesium- or potassium deficiency and even be practically absent (phosphorus deficiency?), or intermediate stages between these deficiency symptoms. Occasionally palms may be observed of the nitrogen deficiency type. The Plant Failure condition sometimes resulting from an attack of Little Leaf disease is probably due to the fact that the impoverished rooting system is unable to absorb the amounts of potassium, magnesium or phosphorus required for normal development from a much smaller and already exploited area.

SUMMARY

CHAPTER 1

The factors limiting the economic life of oil palm plantations are discussed and a review is given of the hazards involved in replanting. The former include the height of the palms, the availability of skilled labour, the production and the cost of harvesting and upkeep. The advantages of replanting as compared to opening up of new areas are reduced by a greater chance of nutrient deficiency- and other diseases.

The seedbed and nursery technique is not principally different for replanted areas, but as the results of recent investigations have suggested some valuable improvements in standard procedures, they have been included in this study, which is mainly concerned with the effect of the old stand and fertilizing on the development of young palms in replanted areas.

CHAPTER 2. SEEDBEDS

The results of our experiments indicate that seedbeds should preferably be made from the black top layer of fresh forest soil (terreau) or a mixture of equal parts of sand and terreau. The depth is of little importance as long as it is sufficient to permit normal development of the seedling and easy removal without serious damage to its rooting system. Shading, when indicated by the weather conditions, should be restricted to the first few weeks after planting, and not be permanent. The spacing in the seedbed is of minor importance if the seedlings are removed within 13 weeks after planting of the germinated seed. The optimum depth of planting is still somewhat uncertain, but probably in the vicinity of 2 cm for unshaded seedbeds made from terreau. Although it is advisable to plant out germinated seed immediately after removal from the germinator, not much damage is done by a delay of as much as six hours if the seeds are protected from direct sunlight. The seed should be planted out when the germ is clearly differentiated into rootlet and first non-functioning leaf, in order to allow for orientated planting to be done.

CHAPTER 3. NURSERIES

From the data provided by our experiments it may be concluded that planting out of germinated seed and four-leaf seedlings directly into the field gives no advantage over the use of planting material reared in nursery beds for replantings under the canopy of the old stand. Planting at stake, however, compares favourably with planting out of four-leaf seedlings. Nurseries should preferably be established on unshaded land. Fertilizing may be recommended as a general practice for establishing nurseries, although it is evident that the benefits will depend on the soil conditions and the fertilizers applied. There appears to be little advantage in applying bunch refuse compost in nursery beds.

CHAPTER 4. EFFECT OF THE OLD STAND

Evidence is presented to suggest that the benefits of retaining the old stand for a certain period of time are greatly reduced by the increased mortality of the young palms, their poor and slow vegetative development, their greater susceptibility to pests and diseases, the retarded beginning of their productive stage and the slow increase of their production. The benefits of fertilizing the young palms became evident in the course of the second year after planting, but are somewhat reduced as long as the old stand is retained. They will, of course, largely depend on the fertility status of the replanted area.

CHAPTER 5. EFFECT OF FERTILIZING

The effects of applications of nitrogen, phosphorus, potassium, magnesium, calcium, copper, manganese, boron, zinc, nickel, cobalt and molybdenum in replanting experiments on a riverine sandy soil in the Basongo Territory and a red latosol in the Basoko Territory, Belgian Congo, are discussed.

From the results obtained it may be concluded that the benefits of applications of nitrogen and calcium are highly uncertain.

Clear, positive responses in terms of yield, health and growth were obtained to applications of phosphorus, potassium and magnesium on the sandy soil and to phosphorus on the latosol.

No certain responses to applications of copper and manganese could be recorded.

Applications of boron prevented Little Leaf disease on both soils, but the responses in terms of yield suggest that correct dosing is very important.

The benefits of applications of zinc, nickel, cobalt and molybdenum are still uncertain, although a mixture of these nutrients improved the health of the palms on the latosol, and zinc and molybdenum on the sandy soil.

The causes of Plant Failure are discussed.

APPENDIX

DESCRIPTION OF THE EXPERIMENTS

SEEDBED EXPERIMENTS (CHAPTER 2)

The seedbed experiments were carried out in a series of bottomless brick bins, each bin representing a 'plot' of one of the experiments. The interior measurements of a bin are 70×70×35 cm. The interior and the top of the walls were covered with a coat of cement. The bins are sunk in the soil, with the walls raised about 5 cm above the surface, and filled in such a way that the surface of the growing medium (sand, terreau or a mixture of sand and terreau) was about level with the surrounding soil. Each individual bin was provided with a 70 cm high wooden frame to carry removable shade curtains made of bamboo slats. The bins were 2 m apart in order to avoid mutual shading in early morning and late afternoon.

Each bin was planted with 49 germinated seeds. Only the seedlings originating from the 25 inside seeds were used for the observations, except the observation on the number of seeds producing one or more plants, which is not likely to be affected by edge effects.

YAL 14. *Seedbed experiment. Influence of growing medium, depth of placement seed, and shading on oil palm seedlings in pre-nursery beds*

Established on the 22nd September 1953 and concluded on the 18th January 1954.

Treatments: A. *Growing medium.*

(1) Sand.
(2) Half sand, half forest top soil (terreau).
(3) Terreau.

B. *Depth of planting.*

(1) Seed just covered.
(2) Seed placed 2 cm deep.
(3) Seed placed 4 cm deep.

C. *Shading.*

(1) Permanently shaded.
(2) Only shaded until the spear shows.

Design: 3×3×2 Factorial experiment in randomized blocks with two replications.

Layout: Thirty-six bins were filled with a 20 cm thick layer of river sand, top soil from the forest (terreau) or a mixture of sand and terreau. In one-third of the bins allocated to each of the above growing media the seed was only just covered; in one-third the seed was placed two cm deep and in one-third four cm deep. Half of the bins allocated to the treatment combinations AB was permanently shaded. From the other half the shade was removed eight weeks after planting. The seedlings were taken up 13 weeks after planting.

YAL 15. *Seedbed experiment. Influence of size of germ, and time between removal from germinator and planting out on seedling.*

Carried out between September 4th and December 15th, 1953.

Treatments: A. *Size of the germ.*

(1) Germ just visible.
(2) Beginning of differentiation in radicle and first leaf.
(3) Clear differentiation of root and first leaf.

B. *Time between removal from germinator and planting out in seedbed.*

(1) Planted out immediately.
(2) Planted out after three hours.
(3) Planted out after six hours.

Design: 3×3 Factorial experiment with two replications.

Layout: 18 Bins were filled with river sand. Each was planted with 49 germinated seeds, the first replication on September 4th and the second replication on September 15th. The seeds were placed 4 cm deep. The shade was removed after the appearance of the first functioning leave. The seedlings were taken up 13 weeks after planting.

YAL 16. *Seedbed experiment. Influence of depth of seedbed and spacing.*
Carried out at Yaligimba between November 2nd 1953 and February 25th 1954.
Treatments: A. *Depth of the seedbed.*
(1) 10 cm.
(2) 20 cm.
(3) 30 cm.
B. *Spacing.*
(1) 5×5 cm.
(2) 7×7 cm.
(3) 9×9 cm.

Design: 3×3 Factorial experiment with two replications.

Layout: Eighteen bins were filled with a 10, 20 or 30 cm thick layer of river sand, and planted with 49 germinated seeds at spacings of 5×5, 7×7 or 9×9 cm, according to the plan. Light shading was provided until the seed came up. The seedlings were taken up 13 weeks after planting and analysed.

NURSERY EXPERIMENTS (CHAPTER 3)

BRAB 7. *Propagation methods for oil palms.*
Established in October 1949 at Brabanta (Basongo) and concluded in October 1951.
Treatments: A. *Planting material and site.*
(1) Nursery plants, grown from germinated seed planted in seedbeds and transplanted to an open nursery on felled forest land when the seedlings were in the four-leaf stage.
(2) Nursery plants, at the same growth stage grown from germinated seed planted in seedbeds and transplanted to a nursery established in the interlines of an adult oil palm plantation.
(3) Seedlings with four leaves, grown from germinated seed planted in seedbeds, planted directly in the field.
(4) Germinated seed planted at stake in the field.
B. *Treatment of the soil.*
(1) No fertilizers, no compost.
(2) Complete fertilizing, no compost.
(3) Compost, no fertilizing.
(4) Fertilizing and compost.

Design: Single blocks for the treatments A; 4×4 Latin Squares for the treatments B.

Layout. A lot of 30.000 illegitimate seeds was placed in germination boxes (VANDERWEYEN 1952, p. 45–49) and removed in October 1949, when 25 per cent of the seed had germinated. Each planting point of the A_4-plots was planted with one germinated and three ungerminated seeds, whilst the remainder was planted out in seedbeds established to provide the planting material for the nurseries A_1 and A_2 and the treatment A_3.

In the beginning of March 1950 a sufficient number of seedlings in the seedbeds had reached the four-leaf stage to allow for planting out twice the number of palms theoretically required for each of the treatments A_1, A_2 and A_3. At this time each point of the plots belonging to treatment A_3 was planted with two seedlings per point, and each of the nurseries A_1 and A_2 was planted with so many seedlings as were required to produce approximately twice the number of palms required for the treatments A_1 and A_2. It is evident that no selection was made when removing the seedlings from the seedbeds. From each line in the seedbed, planted with 5 germinated and 15 ungerminated seeds, 10 seedlings were removed.

Prior to planting out compost was applied to each of the plots receiving the subtreatments B_3 and B_4 of the nurseries A_1 and A_2 and the treatments A_3 and A_4 in the field. The field consisted of an interplanted natural palmery, and the planting was done under the canopy of the old palms.

At the same time fertilizers were applied to the plots receiving the subtreatments B_2 and B_3.

The compost used consisted of well decomposed raffle, and was applied at the rate of 7 kg per palm, representing, when applied in a nursery, about 100 ton per ha. Fertilizers were applied at the rate of 200 kg N, 50 kg P, 183 kg K, 68 kg Mg, 265 kg Ca, 12.5 kg Cu and 0.5 kg B per ha of nursery, and corresponding quantities, viz. 1/143000 th of the ha-application per planting point in the field for the treatments A_3 and A_4. It will be noted that the fertilizer applications were rather high, and that the concentration per point in the field (A_3 and A_4) and in the nurseries (A_1 and A_2) is the same. It was felt that this principle was sounder than applying the same amount of fertilizers to each future palm and consequently halving the rates for the nurseries. Applications of the soluble fertilizers were repeated at the same rates in September 1950, December 1950, and March 1951, when the first stage of the experiment was concluded.

Replacements for the A_1, A_2 and A_3 treatments were made with seedlings originating from the 10 remaining seeds of the above mentioned 20 seeds per line in the seedbed. They were, therefore, potentially the same as the seedlings originating from two of the three ungerminated seeds planted at stake. No replacements were made after November 1950.

YAL 10. *Nursery experiment*

Established February 1952; concluded March 1953.

Treatments: N. *Nitrogen.*
- (0) without N.
- (1) with N.

P. *Phosphorus.*
- (0) without P.
- (1) with P.

K. *Potassium.*
- (0) without K.
- (1) with K.

Mg. *Magnesium.*
- (0) without Mg.
- (1) with Mg.

Ca. *Calcium.*
- (0) without Ca.
- (1) with Ca.

te *Trace elements* (Copper and Manganese).
- (0) without Cu and Mn.
- (1) with Cu and Mn.

Design. 2^6-Factorial experiment with one replication in a 8×8 quasi-Latin Square, with confounding of a number of three-factor interactions. 25 palms per plot.

Layout. Fertilizers were applied at the following rates (kg/ha):

Nitrogen	500 kg nitrochalk (100 kg N)
Phosphorus	125 kg superphosphate 45 % (25 kg P)
Potassium	250 kg sulphate of potash (100 kg K)
Magnesium	350 kg sulphate of magnesia (35 kg Mg)
Calcium	1000 kg ground limestone (350 kg Ca)
Copper	25 kg coppersulphate (6 kg Cu)
Manganese	25 kg manganesesulphate (5 kg Mn)

Calcium was only applied once (February 1952). The applications of the other fertilizers were repeated in May, August and November.

Characteristics of the soils of the experimental areas

	Kanangai Brab 1, 49	Bolembo Elis 3, 4	Wenze Yal 12
Formation	Karroo?	Red Latosol	Red-Yellow Lat.
Territory	Basongo	Basoko	Bumba
Clay (-2 μ) %	6–12	10–30	12–30
Fine sand (20–200 μ) %	±50	40–60	35–50
Coarse sand (200–2000 μ) %	30–35	20–40	30–40
Organic matter %	1.2–1.7	±1	±1
Nitrogen (Kjeldahl) p.p.m.	300–700	300–600	300–800
Total phosphorus p.p.m.	100–200	10–200	30–200
Phosphorus fixation	none	high	high
Total potassium p.p.m.	50–300	400–2000	100–200
pH	4.3–4.7	4.2–4.7	4.3–5.0

BRAB 1. *Replanting experiment Kanangai (Basongo).*
Replanted November 1948.
First manuring November 1948.

Treatments: (i) Young palms planted under the canopy of the old palms. No fertilizers applied.
(a) Old palms felled before planting of the young palms. No fertilizers applied.
(b) Young palms planted under the canopy of the old palms. Fertilizers applied.
(ab) Old palms felled before planting of the young palms. Fertilizers applied.

Design: One 4×4 Latin Square. Plots of 78 palms, separated and surrounded by one single guard row.

Layout: The old stand on the plots assigned to the (i) and (b) treatments was removed by means of poisoning in the course of 1952. In the plots assigned to the (b) and (ab) treatments the following quantities of nutrients were applied (gms per palm per annum):

Year	N	P	K	Mg	Ca
1948	23	26	66	10	163
1949	70	23	91	35	82
1950	192	48	175	65	131
1951	256	–	234	–	–
1952	308	78	298	–	80
1953	308	78	298	–	294

Nitrogen was applied as ammoniumphosphate (1948, 1949, 1950), nitrochalk (1949, 1950, 1952, 1953) and ammoniumsulphate (1951); phosphorus as ammoniumphosphate (see nitrogen) and superphosphate 45 % (1952, 1953); potassium as potassiumsulphate (all years); calcium as dolomitic limestone (1948) and calciumcarbonate (1949), apart from the quantities contained in the other fertilizers (nitrochalk, superphosphate); magnesium as dolomitic limestone (1948) and magnesiumsulphate (1949, 1950). Trace elements were applied in 1950 only, viz. 25 gm copper as coppersulphate, 1.1 gm boron as borax, 0.8 gm zinc as zincsulphate, 0.8 gm nickel as nickelsulphate, 0.8 gm cobalt as cobaltsulphate and 1.9 gm molybdenum as ammoniummolybdate.

BRAB 49. *Replanting experiment Kanangai (Basongo).*
Replanted March 1948 after partial removal of the old stand. First manuring February 1953 after complete removal of the old stand.

Treatments: (1) Complete fertilizing.
(2) As (1) with omission of nitrogen.
(3) As (1) with omission of phosphorus.
(4) As (1) with omission of potassium.
(5) As (1) with omission of magnesium.
(6) As (1) with omission of calcium.
(7) As (1) with omission of copper.
(8) As (1) with omission of manganese.
(9) As (1) with omission of boron.
(10) As (1) with omission of zinc.
(11) As (1) with omission of nickel.
(12) As (1) with omission of cobalt.
(13) As (1) with omission of molybdenum.
(14) Control (no fertilizers applied).

Design: Randomized blocks with 14 treatments and 4 replications. 16 palms per plot.

Layout: Complete fertilizing comprised the application of nitrogen, phosphorus, potassium, calcium, magnesium, copper, manganese, boron, zinc, nickel, cobalt and molybdenum, viz.:

	1953	1954
N	1.500 kg sulphate of ammonia	do.
P	0.500 kg superphosphate 45 %	do.
K	0.750 kg sulphate of potassium	do.
Mg	1.000 kg sulphate of magnesium	do.
Ca	3.000 kg ground limestone	nil
Cu	0.167 kg coppersulphate	0.25 % spray
Mn	0.167 kg manganesesulphate	0.25 % spray
B	0.017 kg borax	1.00 % spray
Zn	0.007 kg zincsulphate	1.00 % spray
Ni	0.007 kg nickelsulphate	0.10 % spray
Co	0.007 kg cobaltsulphate	0.10 % spray
Mb	0.007 kg ammoniummolybdate	0.10 % spray

YAL 12. *Replanting experiment Wenze (Bumba).*

Replanted September 1952 and 1953. First manuring and first removal of the old stand September 1953.

Treatments: Whole plot treatments.

(i) Old stand completely removed.
(ii) 2/3rd of the old stand removed.
(iii) 1/3rd of the old stand removed.
(iv) No removal of the old stand.

Sub-plot treatments.

A1 Young palms fertilized.
A2 No fertilizers applied.

Design: One 4×4 Latin Square for the whole plots. Each whole plot split into four sub-plots, two fertilized and two non-fertilized. The number of palms per whole plot amounts to 90, that per sub-plot to 20 or 25.

Layout: Removal of 1/3rd of the old stand was done by poisoning the sterile and inproductive palms in each line. Removal of 2/3rd of the old stand consisted of felling of alternate lines and removal of 1/3rd of the palms in the remaining lines. The productions obtained from the old stand for the whole plot treatments, expressed as a percentage of no removal (iv), amounted to 52 % if 2/3rd and 96 % if 1/3rd was removed.

The fertilizing applied to the young palms consisted of:

500 gm nitrochalk,
250 gm potassiumsulphate,
350 gm magnesiumsulphate,
100 gm double superphosphate (45 % P_2O_5),
5000 gm rockphosphate.

ELIS 3. *Replanting experiment Bolembo (Basoko).*

Replanted March 1950 after complete removal of the old stand. First application of fertilizers March 1952.

Treatments: N. Nitrogen.
- 0 no nitrogen,
- 1 single dressing of nitrogen fertilizer,
- 2 double dressing of nitrogen fertilizer.

P. Phosphorus.
- 0 no phosphorus,
- 1 single dressing of phosphorus fertilizer,
- 2 double dressing of phosphorus fertilizer.

Design: 3×3 Factorial experiment with 3 replicates in blocks of 9 plots. Number of palms per plot 36.
Layout: Fertilizers were applied in March 1952 and September 1953 at the following rates:

March 1952.
N_1 = 1200 gm ammoniumsulphate.
N_2 = 2400 gm ammoniumsulphate.
P_1 = 900 gm rockphosphate.
P_2 = 1800 gm rockphosphate.

September 1953.
N_1 = 1000 gm nitrochalk.
N_2 = 2000 gm nitrochalk.
P_1 = 5000 gm rockphosphate.
P_2 = 10000 gm rockphosphate.

ELIS 4. *Replanting experiment Bolembo (Basoko).*

Replanted December 1949 after complete removal of the old stand. First application of fertilizers March 1952.

Treatments: K. Potassium.
- 0 no potassium.
- 1 with potassium.

Mg. Magnesium.
- 0 no magnesium.
- 1 with magnesium.

Ca. Calcium.
- 0 no calcium.
- 1 with calcium.

Cu. Copper.
- 0 no copper.
- 1 with copper.

Mn. Manganese.
- 0 no manganese.
- 1 with manganese.

B. Boron.
- 0 no boron.
- 1 with boron.

te. Trace elements (zinc, nickel, cobalt, molybdenum)
- 0 no trace elements.
- 1 with trace elements.

Design: 2^7-Factorial experiment with 1/8th replicate. Number of palms per plot 36.

Layout: Fertilizers were applied in March 1952 and September 1953 at the following rates per palm (gm):

	III/1952	IX/1953	Fertilizer
K_1	1100	1000	potassiumsulphate
Mg_1	1500	1000	magnesiumsulphate
Ca_1	6400	nil	ground limestone
Cu_1	320	0.25 % spray	coppersulphate
Mn_1	320	0.25 % spray	manganesesulphate
B_1	32	1.00 % spray	borax
te_1	13	spray	see below

The first application of trace elements consisted of 13 gm of a mixture containing equal weights of zincsulphate, nickelsulphate, cobaltsulphate and ammoniumsulphate, the second of a spray containing 1.00 % zincsulphate and 0.10 % of each of the other trace elements.

REFERENCES

BACHY, A. 1949 Etude sur le „Boyomi" et quelques autres maladies graves du palmier en Afrique. *Oléagineux;* **4,** 7: 421–426.

——— 1954 Contribution à l'étude de la pourriture du coeur du palmier à huile. *Oléagineux;* **9,** 8–9: 619–627.

BARTHOLOMEW, W. V., J. MEYER & H. LAUDELOUT 1953 Mineral nutrient immobilization under forest and grass fallow in the Yangambi (Belgian Congo) region. *Publ. I.N.E.A.C.,* Sér. Sc. No 57.

BELGRAVE, W. N. C. 1932 Oil palm manurial experiments. *Malayan Agr. J.;* **20,** 6: 304–306.

——— & J. LAMBOURNE 1933 Manurial experiments on coconuts and oil palms. *Malayan Agr. J.;* **21,** 5: 206–216.

——— 1935 Manurial experiments on oil palms. *Malayan Agr. J.;* **23,** 7: 321–335.

——— & J. LAMBOURNE 1937 Manurial experiments on oil palms. *Malayan Agr. J.;* **25,** 7: 286–296.

BLANK, S. DE 1952 A reconnaissance of the American oil palm. *Trop. Agr. Trinidad* **29,** 4–6: 90–101.

BROESHART, H. 1954a The use of foliar analysis in oil palm cultivation. *Trop. Agr. Trinidad* **31,** 3: 251–260.

——— 1954b The use of foliar analysis in oil palm cultivation. Communication Vth International Congress of Soil Science, Léopoldville.

——— 1955 The application of foliar analysis in oil palm cultivation. Thesis Wageningen 1955.

BUCKLEY, T. A. 1951 Notes on the control of trees and weeds by phytocides. *Malayon Agr. J.;* **34,** 1: 27–31.

BULL, R. A. 1954a A preliminary list of the oil palm diseases encountered in Nigeria. *J. W. Afr. Inst. Oil Palm Res.* **1,** 2: 53–93.

——— 1954b Studies on the deficiency diseases of the oil palm: 1. Orange Frond disease caused by magnesium deficiency. *J. W. Afr. Inst. Oil Palm Res.* **1,** 2: 94–129.

BUNTING, B. 1932 Experiments on the manuring of coconuts and oil palms. *Malayan Agr. J.* **20,** 3: 105–112.

———, C. D. V. GEORGI & J. N. MILSUM 1934 The oil palm in Malaya. Kuala Lumpur.

CHAPMAN, G. W. & H. M. GRAY 1949 Leaf analysis and the nutrition of the oil palm (Elaeis guineensis Jacq.) *Ann. Bot. XIII,* 52: 415–433.

DENNETT, J. H. 1938 Manurial experiments on oil palms. *Malayan Agr. J.* **26,** 7: 273–281.

FERRAND, M. 1947 La culture du palmier à huile. *Oléagineux* **2,** 1: 1–10.

——— 1947 Fumure chimique et entretien de la fertilité des sols dans les plantations de palmier à huile. *Oléagineux* **2,** 12: 617–629.

——— & M. OLLAGNIER 1950 Premiers résultats des essais de fumure minérale sur le palmier à huile à Dabou. *Oléagineux* **5,** 4: 227–233.

———, A. BACHY & M. OLLAGNIER 1951 Les oligoéléments dans la fumure du palmier à huile au Moyen-Congo. *Oléagineux* **6,** 11: 629–636.

———, M. OLLAGNIER & P. BOYE 1952 Résultats des premiers essais de fumure minérales sur les palmiers à huile en Côte d'Ivoire. *Oléagineux* **7,** 6–7: 553–556.

———, A. BACHY & M. OLLAGNIER 1951 Les carences en oligo-éléments dans les sols du Moyen-Congo. *C. R. Séan. Acad. Sci.,* Paris **CCXXXIII,** 20: 1218–1220.

FERWERDA, J. D.	1954a	Boron deficiency in oil palms in the Kasai region of the Belgian Congo. *Nature*, London **173**: 1097.
———	1954b	Fertilizing of the African Oil Palm. Communication Vth Int. Congress of Soil Sci., Léopoldville.
FRASELLE, J. V.	1953	Inspection phytosanitaire de quelques palmeraies du Mayumbe. *Bull. Agr. Congo Belge* **44**, 1: 75–90.
FREMOND, Y. & A. ORGIAS	1952	Contribution à l'étude du système radiculaire du palmier à huile. *Oléagineux* **7**, 6: 345–350.
GEORGI, C. D. V.	1931	Removal of plant nutrients in oil palm cultivation. *Malayan Agr. J.* **19**, 10: 484–489.
GHESQUIERE, J.	1935	Etat sanitaire de quelques palmeraies de la province de Coquilhatville. *Publ. I.N.E.A.C. Sér. Sci.* No. 3.
HALE, J. B.	1947	Mineral composition of leaflets in relation to the chlorosis and bronzing of oil palms in West Africa. *J. Agr. Sci.* **37**, 3: 236–244.
HARTLEY, C. W. S.	1948	A demonstration of mechanical cultivation at the central experimental station, Serdang. *Malayan Agr. J.* **31**, 2: 127–131.
———	1949	The felling and disposal of old palms prior to replanting. *Malayan Agr. J.* **32**, 3: 223–230.
———	1950	The effect of a potassium magnesium fertilizer on the yield of oil palms on hill quartzite soil. *Malayan Agr. J.* **33**, 1: 38–41.
HEIM, R. & A. BACHY	1949	Observations préléminaires sur une grave maladie du palmier à huile sévissant au Congo français. *C. R. Séan. Acad. Sci.*, Paris, **228**, 3: 217–220.
HEURN, F. C. VAN	1948	De oliepalm. De landbouw in de Indische Archipel. Deel IIA. Voedingsgewassen en geneesmiddelen. 's-Gravenhage.
HOMÈS, M. V.	1949	L'alimentation minérale du palmier à huile. *Publ. I.N.E.A.C.*, Sér. Sc. No 39.
———	1952	L'utilisation des engrais au Congo belge. *Bull. Inf. I.N.E.A.C.* I, 1 + 2: 21–36.
———	1954	Comm. Vth Int. Congr. Soil. Sci. Léopoldville.
INEAC		Institut National pour l'Etude Agronomique du Congo belge (I.N.E.A.C.). Rapports annuels 1936–1952.
IRHO		Institut de Recherches pour les Huiles et Oléagineux (I.R.H.O.). Rapports annuels 1951–1953.
JAGOE, R. B.	1952	'Deli' oil palms and early introductions of Elaeis guineensis to Malaya. *Malayan Agr. J.* **35**, 1: 3–11.
———	1952	The 'dumpy' oil palm. *Malayan Agr. J.* **35**, 1: 12–21.
JULIA, H. & J. ABELÉ	1947	Observations comparées sur la végétation et la précocité de jeunes palmiers à huile. *Oléagineux* **2**, **4**: 208.
KOVACHICH, W. G.	1952	Abnormal roots in oil palms in the Belgian Congo. *Trop. Agr. Trinidad* **29**, 1–3: 29–34.
———	1952	Little Leaf disease of the oil palm (Elaeis guineensis) in the Belgian Congo. *Trop. Agr. Trinidad* **29**, 4–6: 107–114.
———	1953	Little Leaf disease of the oil palm (Elaeis guineensis) in the Belgian Congo. *Trop. Agr. Trinidad* **30**, 1–3: 61–69.
LAMBOURNE, J.	1935	Note on the root habit of oil palms. *Malayan Agr. J.* **23**, 12: 582–583.
LAUDELOUT, H.	1950	Etude pédologique d'un essai de fumure minérale de l'Elaeis à Yangambi. *Publ. I.N.E.A.C.*, Sér. Sci. No 47.
LOUVRIER, J.	1951	Rendements comparés de jeunes palmeraies établies sur forêt ancienne et sur jachère arbustive. *Oléagineux* **6**, 8–9: 522–523.
LUC, M.	1954	Sur un cas de 'Leaf Bend' du palmier à huile en Côte d'Ivoire. *Oléagineux* **9**, 3: 161–163.
MAAS, J. G. J. A.	1922	A. A. L. Rutgers, Investigations on oil palms. Batavia.
MALAYA		Anonymous communications on current investigations under the auspices of the Department of Agriculture, Federation of

		Malaya, in the Malayan Agricultural Journal. Since 1950 'Notes on current investigations. Oil Palm'. *Malayan Agr. J.* **28,** 11: 471 (1940); **33,** 2: 101 (1950); **33,** 3: 166–167 (1950); **33,** 4: 231 (1950); **34,** 1: 46 (1951); **34,** 2: 88 (1951); **34,** 3: 136 (1951); **34,** 4: 215 (1951); **35,** 1: 42 (1952); **35,** 2: 109 (1952); **35,** 3: 170–171 (1952); **36,** 1: 39 (1953); **36,** 2: 118 (1953); **36,** 3: 195 (1953); **36,** 4: 252 (1953); **37,** 1: 26 (1954); **37,** 3: 183 (1954).
MICHAUX, P.	1953	Le rajeunissement des palmeraies. *Oléagineux* **8,** 7: 459–461.
OPSOMER, J. E.	1932	Notes sur l'Elaeis à la Côte Est de Sumatra. *Bull. Agr. Congo Belge* **23,** 4: 422–471.
PREVOT, P. & M. OLLAGNIER	1953	Engrais minéraux et oléagineux tropicaux. II. Palmier à huile. *Oléagineux* **8,** 12: 843–851.
RANCOULE, A. & M. OLLAGNIER	1952	Fumure minérale du palmier à huile. *Oléagineux* **7,** 7: 391–395.
RINGOET, A.	1952	Recherches sur la transpiration et le bilan d'eau de quelques plantes tropicales. *Publ. INEAC, Sér. Sci.* No 56.
SCHEIDECKER, D. & P. PREVOT	1954	Nutrition minérale du palmier à huile à Pobé (Dahomey). *Oléagineux* **9,** 1: 13–19.
THOMPSON, A.	1940	Notes on plant diseases. *Malayan Agr. J.* **28,** 9: 400–401.
	1941	*Malayan Agr. J.* **29,** 6: 241–242.
VANDERIJST, H.	1921	Notions botanico-agronomiques élémentaires concernant les racines de l'Elaeis. *Bull. Agr. Congo Belge* **12,** 3: 506–522.
VANDERWEYEN, R. & O. ROELS	1949	Les variétés d'Elaeis guinéensis Jacquin du type albescens et l'Elaeis melanococca Gaertner. *Publ. I.N.E.A.C.,* Sér. Sci. No 42.
VANDERWEYEN, R.	1952	Notions de culture de l'Elaeis au Congo belge. Min. Colonies Bruxelles.
VANDERWEYEN, R.	1953	Le croisement 'dura×pisifera' et ses premiers résultats. *Bull. Inf. I.N.E.A.C.* **2,** 2: 123–136.
WAIFOR,	1953	West African Institute for Oil Palm Research. *First Annual Report 1952–1953.*
WARDLAW, C. W.	1946	A wilt disease of the oil palm. *Nature,* London **158,** 4002: 56.
———	1946	Fusarium oxysporum on the oil palm. *Nature,* London **158,** 4020: 712.
———	1948	Vascular wilt disease of oil palms in Nigeria. *Nature,* London **162,** 4126: 850–851.
———	1950	Vascular wilt disease of the oil palm caused by Fusarium oxysporum Schl. *Trop. Agr. Trinidad* **27,** 1–3: 42–47.
———	1950	Armillaria root and trunk rot of oil palms in the Belgian Congo. *Trop. Agr. Trinidad* **27,** 4–6: 95–97.
WATERSTON, J. M.	1953	Observations on the influence of some ecological factors on the incidence of oil palm diseases in Nigeria. *J. W. Afr. Inst. Oil Palm Res.* 1: 24–59.
WILBAUX, R.	1937	Les besoins du palmier à huile en matières nutritives. *Bull. Agr. Congo belge* **28,** 4: 574–586.
WILSHAW, R. G. H.	1940	Manurial experiments on oil palms. *Malayan Agr. J.* **28,** 6: 258–275.
WRIGHT, J. O.	1951	Unusual features of the root system of the oil palm in West Africa. *Nature,* London **168,** 4278: 748.
YAMPOLSKI, C.	1924	The pneumatodes on the roots of the oil palm. Amer. J. Bot. **11,** 8: 502.
ZELLER	1911	Die Düngungsfrage für die Kultur des Kakao und Ölpalme in Kamerun. *Der Tropenpflanzer* **15,** 7: 345–359.