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Verheye, W.

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GROWTH AND PRODUCTION OF OIL PALM

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Keywords : Agro-chemicals, estate, fresh fruit bunch, industrial plantations, land clearing, land management, oil palm, palm kernels, palm oil, pests.

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Summary

Oil palm is a tropical tree crop which is mainly grown for the industrial production of vegetable oil. For optimal growth and production the crop requires a high and year-round rainfall with little or no dry season and stable high temperatures; soils should be deep and well drained. The crop grows mainly in tropical lowlands below 400m altitude, originally covered by a dense rainforest. Dry spells or temperatures below 18° C do not affect vegetative growth but reduce yield. Fertilizer demands are moderate compared to other industrial crops and are mainly for compensating the nutrients harvested in the fruit bunches.

The crop is sensitive to many pests and diseases. As those affect quite seriously yield and economic profit, estate managers should pay due attention to control and/or eradication of such pests and diseases.

Oil palm is now the most important supplier of vegetable oil in the world. There are 3 oil palm varieties: *Dura*, *Pisifera* and *Tenera*, with the latter being mainly selected for economic production. The oil is concentrated in the fruit bunches, composed of a fresh fruit pulp, and in the fruit kernels. Oil content in the fruit pulp is about 50-60% or 20-22% of bunch weight; oil content in the fruit

kernels is 48-52% or 2-3% of bunch weight. Fresh fruit bunches once harvested must be treated in an oil mill within 24 hours to avoid that oil quality decreases.

Palm oil has for a long time been considered a relatively low-value edible oil because of the difficulty in manipulating its fatty acid profile. Recent research has gradually upgraded this perception, and palm oil is now becoming a high-value niche product in the health food sector.

1. Introduction

Oil palm (*Elaeis guineensis*) is a tropical tree crop which is mainly grown for its industrial production of vegetative oil. It is a typical estate crop, grown and harvested over large uniform areas (3,000 to 5,000 ha) around a central oil mill to allow rapid industrial handling after harvesting. Palm trees can also be observed in village gardens where they provide oil for local consumption, but in that case both yield and oil quality are much lower.

Oil palm is a typical crop of the rainy tropical lowlands. The tree requires a deep soil, a relatively stable high temperature and continuous moisture throughout the year. Soil fertility is less important than physical soil properties. Dry periods of more than 2-3 months do not specifically damage vegetative growth, but affect seriously the production and quality of the fruit bunches. Oil palm yields is not only determined by vegetative growth and production, but also by the way and pests and diseases can be controlled or eradicated.

Because industrial oil palm plantations need the clearance of large areas they often require the expropriation of land and the cutting of extensive (pristine) forest areas. Hence, the development of such plantations is usually associated with land tenure conflicts and problems of local land ownership on one hand and ecological problems, viz. biodiversity loss, on the other hand.

2. Origin and Distribution

The origin of oil palm points to Africa, in particular to West Africa. Fossil pollen, similar to the oil palm as it grows today, have been found in Miocene and more recent strata in the Niger delta. Portuguese explorers of the Guinea coast mention the existence of trees appearing to be oil palms as early as 1434. In 1508 already reference has been made to palm groves in Liberia, and to palm oil trade near the Forcados River in Nigeria. Later, Portuguese, Dutch and English travelers refer to palm wine and palm oil in the area.

The centre of origin of oil palm is the West and Central African coastal belt between Guinea and northern Angola. The palm spreads from 16° North in Senegal to 15° South in Angola, and eastwards to Zanzibar and Madagascar. The best production levels are attended in the high rainfall areas between 7° North and South from the Equator.

Oil palms are sporadically encountered up to St. Louis in Senegal and to the Upper Niger valley near Bamako. Minor palm groves are observed around Dakar and in the Gambia, but their production is too low to justify the establishment of commercial oil mills. The real palm belt in Africa runs through the southern latitudes of Guinea, Sierra Leone, Liberia, Ivory Coast, Ghana, Togo, Benin, Nigeria, Cameroon and into the equatorial regions of Equatorial Guinea and the Congo. The northern limit of this belt varies with the isohyets of 1200mm rain per year and with the topography of 400m altitude. There is a small area surrounding Accra where due to low rainfall (less than 650 mm/year), oil palm estates are absent.

The extension of oil palm in East Africa is irregular. Most of East and South-East Africa is too dry and, therefore, the crop appears only at altitudes below 1,000m near lakes or watercourses with

reasonable rainfall. Its presence on the eastern coast of Madagascar is due to a local microclimate, though in this area the crop can be affected by tornados.

In the Far East palms were initially only grown as ornamental plants. Seed selection in the Botanic Gardens of Singapore and Bogor (Java, Indonesia) and at the Deli Research Center in Sumatra (Indonesia) gave origin to an important development and extension of the crop since the 1930s in Malaysia and Indonesia. These are now the main production areas in the world, both in terms of palm oil and palm kernel production (Table 1). The yield and quality of palm oil produced in these areas is still superior to the oil produced in other parts of the world. Oil palm plantations in Latin America are relatively recent.

Table 1: Palm oil and palm kernel oil production in the world
(Sources: FAO Yearbooks and <http://www.unctad.org>)

3. Botany

The oil palm tree (*Elaeis guineensis*) is a member of the family *Palmae*, subfamily *Coccoideae* (which also includes the coconut), genus *Elaeis*. The genus contains two main species: *E. guineensis* or African oil palm, and *E. melanococca* or American oil palm; the latter is only valuable for hybridization. Male and female inflorescences occur on the same tree in alternated cycles of the same sex, and are only differentiated after approximately two years. This process is influenced by moisture and temperature conditions, fertilization and other secondary ecological factors.

The development of the inflorescence to the fruit regime takes 42 months, including 10 months from establishment to initial sexual differentiation, 24-26 months between sex development and flowering, and 5-6 months from flowering to yield. Hence, ecological conditions which affect earlier phases of inflorescence and flowering appear only in the yields 18 to 24 months afterwards. This situation opens good perspectives for good yield forecasting (see chapter 5.2).

3.1 Cultivars and Classification

Cultivars in the strict sense do not occur. As the oil palm is monoecious and cross-pollinated, individual palms are usually very heterozygous; and vegetatively propagated clonal material can not be made. The current classification of cultivars is mainly based on fruit structure and yield (or commercial value):

- *Macrocaria* : shell (endocarp) 6-8mm thick; is an extreme form of *Dura*, which is still widely spread in Sierra Leone and western Nigeria; without any commercial value;
- *Dura*: shell 2-8mm thick, comprising 25-55% of weight of fruit, medium mesocarp content of 35-55% by weight, but up to 65% in Deli palms; less productive but hardy variety, well adapted to village gardens;
- *Pisifera*: shell-less, with small pea-like kernels in fertile fruits; of little commercial value, because of its high abortion ratio, but important for cross-breeding commercial palms; and
- *Tenera*: shell 0.5-3mm thick; comprising 1-32% of weight of fruit; medium to high mesocarp content of 60-95%, but occasionally as low as 55%; this variety is the result of a hybridization of *Dura* and *Pisifera*, and has a high commercial value.

Most commercial plantations are established on the basis of *Tenera* palms. Oil palms may live up to 200 years, but their commercial yield rapidly decreases after 30 years of age (Figure 1).

Figure 1. Oil palm plantation of about 12 years old. The stipe is covered by old bases

Of leaves which were cut during harvesting and maintenance pruning (courtesy D. Cornet).

3.2 Structure

Oil palm is an un-branched, 20 to 30m high tree. **Roots** arise from the base of the hypocotyl and later from the basal bole of the stem. Primary roots descend deeply from the base of the trunk, but remain short when the water table is high. Otherwise they produce secondary, tertiary and quaternary roots that form a dense mat in the immediate neighborhood of the tree. Most roots are found in the top 15cm of the soil, with a main concentration near the palm and a secondary concentration 1.5 to 2m from the base.

The early growth from the seedlings results in the formation of a wide **stem (stipe)** base. A trunk is not formed until 3 years old when the apex has reached its full diameter in the form of an inverted cone, after which intermodal elongation takes place. The rate of extension then depends on environmental and hereditary factors, and varies between 25 and 50cm per year.

The **leaves** are produced in spiral succession from the meristem. The crown consists of 40-50 opened leaves in various stages of development. One leaf is produced per month until the seedling is 6 months old. The number of leaves produced increases to 30-40 per year at 5-6 years old and later declines to 18-25. The life of a mature leaf after unfurling is about 2 years. The leaf area of an adult palm is around 400 m² (Figure 2).

Figure 2. Young oil palm of three years old; note the cover crop (*Pueraria*) in the interrow (Courtesy D. Cornet)

Flowering starts after the young palm has well established (Figure 3). An inflorescence primordium is produced in the axil of each leaf at the time of leaf initiation. The inflorescence reaches the central spear stage in two years and a further 9-10 months is required to flowering and anthesis. Each flower primordium is a potential producer of male and female inflorescence (see sex ratio below). The number of inflorescences per palm depends on the number of leaves produced and the number of inflorescences which reach maturity without abortion.

Inflorescences - Male and female inflorescences form separately on the same palm. A male inflorescence produces 10-40g of pollen, i.e. millions of grains. A female inflorescence consists of a central stalk (peduncle) to which spikelets are attached. On these spikelets one finds the tiny 1 cm-diameter cream-colored female flowers.

Figure 3: *Elaeis guineensis* (Purseglove, 1976; [Permission still to be obtained](#)).

(A: Palm tree; B: portion of leaf rachis; C: base of rachis; D: male inflorescence; E: male spike; F: male spike in transverse section; G: male flower in longitudinal section; H: portion of female inflorescence; I: female flower; J: fruit bunch; K: fruit; L: fruit in longitudinal section).

Sex ratio - The proportion of female to total inflorescences, must be high to obtain high yields, but the order and proportion of male and female inflorescences shows little regularity. The period between sex differentiation and anthesis is about 2 years. The sex ratio is partly genetic and partly determined by climatic and other environmental conditions at the time of floral determination.

Fruiting and harvesting - The time from flowering to harvesting of ripe fruits is 5-6 months. The fruit bunch is tightly wedged in the leaf axil of the palm. A bunch of a mature palm contains 1,000 to 4,000 fruits, depending on the tree's age and vigor. A bunch weights at maturity 15-25kg, but can occasionally reach over 50kg (Figure 4). The percentage of fruits per bunch is usually 50-65% and

is lower in Tenera than in Dura due to the thicker shell of the latter. The egg-shaped fruits weigh 10-20g. The pulp (mesocarp) around the nut contains the red palm oil. The kernel in the nut contains an oil very similar to coconut oil, but palm oil and palm kernel oil are chemically different.

Figure 4. Fresh fruit bunch (Courtesy D. Dewaele)

3.3 Pollination and Propagation

Oil palms are cross *pollinated*. Pollen are dry and are mainly wind-born over at least 30m. Male flowers are anise-scented and are visited by insects, particularly bees, but these do not visit the male flowers. Assisted pollination is given in modern plantations in order to increase yields.

Naturally distributed seeds do not germinate readily, and while awaiting favorable seasonal conditions, many of them might be destroyed by rodents or boring beetles. In West Africa they remain often dormant during the dry season and start germinating 6-10 weeks after the start of the first rains. A high temperature is required for satisfactory germination: 30-40° C for 80 days at a moisture content above 14.5%, followed afterwards by ambient temperatures and moisture contents of 21-22% (for *Dura*) or 28-30% (for *Tenera*).

Seeds can be stored for at least a year at ambient temperatures. Germinated seeds, transported in polythene bags or packed in boxes, can remain in the bags for up to ten days before planting. Germinated seeds are planted in pre-nursery beds, trays, baskets or bags. After 4-5 months, when the seedlings reach the 4-5 leaf stage, they are transferred to field nurseries or large polythene bags where they grow for 6-12 months before transplanting to the field.

4. Ecology and Growing Conditions

Oil palm is a typical tree crop of the tropical rainforest. It can however hardly survive or regenerate in dense secondary forest because of the lack of sunshine. This is also the reason why stand-alone trees in villages are generally much taller than in palm groves. For optimal growth and production the tree requires stable climatic conditions, in particular with respect to light and moisture supply. Any deviation from these conditions enhances a yield decrease.

Oil palm thrives best in lowlands below 300-400m altitude. Under a favorable microclimate it can also occur at much higher altitudes, as is the case on Mount Cameroon, where palms are observed up to 1,300m elevation, or in the Fouta Djallon area in Guinea. In East Africa palm trees can be found at altitudes up to 1,000 m.

4.1 Climate Requirements

Temperature – Temperature requirements for oil palm are simple and straight forward. High temperatures are favorable with as less as possible fluctuations. Below 18° C growth is stopped. The optimal daily temperature is 27-28° C, with mean monthly values between 30-32° C maximum and 21-24° C minimum. The mean minimum temperature of the coldest month should be > 18° C. Seedling growth is arrested at temperatures < 15° C.

Investigations in Congo and Guinea have indicated that night temperatures below 15° C might cause “heart rot”, a disease which develops in trees of 5 to 8 years old, starting at the centre of the crown and leading often to a dying of the palm. As it is difficult to replant trees in an affected grove because of the reduced sunlight interception, this results in a loss of production for at least 20 years.

Rainfall and moisture – Oil palms require an average rainfall of 150 mm/month, with dry periods not exceeding 2-3 months. Relative air humidity should be above 75% throughout the year.

On average, a minimum annual rainfall of 1,800mm is considered optimal, ranging up to 2,500mm without harm. Rainfall above 2,500mm is considered unfavorable because this interferes with a lower solar radiation. In Malaysia it is found that 2,000mm rain per annum produces the best yields. On Mount Cameroon oil palm production is possible in high rainfall areas (over 4,500 mm/year) because rains concentrate in short but heavy afternoon showers leaving sufficient sunshine hours in between the rains.

Oil palms can tolerate temporary flooding, provided the water is not stagnant, and the water table is fluctuating.

Moisture balance – The moisture regime of an oil palm grove can rapidly and rather accurately be defined through a soil water balance. This requires rain data (P) for individual years on a monthly or 10-day basis since the use of annual averages might mask intermediate drought occurrences. The method developed by IRHO (Ochs, 1977) for West Africa is still considered the standard in this respect. In this approach the maximum water storage capacity of the soil (WS) is assumed to be 200mm (this figure may be lowered in the case of coarser textured soils), and evapotranspiration (ETP) or water loss is assessed between 150mm (for months with 10 or less rainy days) and 120mm per month (for months with more than 10 rainy days). The water balance (WB) is calculated from the formula:

$$WB \text{ (mm)} = P + WS - ETP$$

If WB is negative (< 0) the value corresponds with the effective moisture deficit. If WB is between 0 and 200mm, the value indicates the presence of plant available water and this can be considered as the initial WS of the following month (or 10-day period). If WB exceeds 200, this indicates the presence of ample soil moisture (even beyond the storage capacity of the soil), and the WS transfer to the following month is limited to 200mm, being the maximum soil water storage. The length of the dry season deficit is the total of the monthly deficits. The effect of the length of the dry season is expressed in the following (climatic) suitability rating:

- the yearly deficit is between 0 and 150mm: growth conditions are considered (nearly) optimal;
- deficit between 150 and 250mm: growth conditions are quite favorable;
- deficit is between 250 and 350mm: conditions are considered intermediate and a serious yield reduction can be expected; a few irrigations might be needed;
- deficit is between 350 and 500mm: borderline conditions and a cost-benefit study is required before economic production can be started; if market conditions are very favorable the installation of an irrigation network might be taken into consideration;
- deficit is more than 500mm per year and the dry season is more than 4 months: conditions are definitely unfavorable.

An almost continuous moisture supply is a critical factor for high oil palm yields. A moisture deficit affects the yield in four main ways:

- a severe moisture deficit causes abortion of inflorescences, both male and female, about 4 months prior to anthesis, resulting in a more or less important crop reduction some 10 months after the period of stress;
- physiological stress due to any cause, at the time of sex determination of the floral initials results in the formation of a much higher number of male inflorescences, which adversely affects yields of mature palms about 26 months or later;

- during periods of severe moisture stress, abortion of newly-produced inflorescences can occur, together with drying out and death of developing fruit bunches;
- there is some experimental evidence that a deficit also affects production adversely 3 years later.

In addition, moisture deficits affect also management and plantation practices, as for example in:

- the adaptation of the field planting program, because young trees need a minimum period for establishment and for developing a proper root system before the onset of the next dry season. In the adverse case, initial yields might be adversely affected;
- the timing of fertilizer applications, as it is important to ensure that nutrients are taken up properly and exert maximum effects on yields;
- the planting of the cover crop (see: chapter 5. Crop and Land Husbandry) must be done at the time of the onset of regular rains to gain maximum soil improvement.

Effect on oil mill operations - The rainfall affects crop production over the year. Without a moisture deficit fruit production should be quite continuous over the year, with an approximate maximum 12.5% of the year production concentrated in the peak crop month. In areas with a severe moisture deficit (and irregular rainfall pattern), the year production is uneven and the peak month can have up to 15-16% of the annual production, while in other months the yield is definitely lower. In other words, depending on the rainfall regime the mill activity might be forced to slow down in some part of the year, and the oil mill exploitation might become less economic.

Solar radiation and shading - A high level of solar radiation is important for growth and fruit bunch production. Farmers know that oil palms in the open field are often more productive than under a closed canopy. Even in one and the same plantation, side-rows along plantation fields frequently produce more than inner rows.

Authors differ in their estimations of optimal sunshine hours (between 1,800 and 2,200 hours per year), but it is generally accepted that at least 5 hrs of sunshine per day in all months is desirable, rising to 7 hrs per day in some months. This is usually the case in Malaysia and Sumatra, and this explains why production levels there are often higher than in Africa. Purseglove (1976) notes also that the sex ratio is highest when there have been long periods of sunshine two years previously at the time of flower differentiation and when the dry season rainfall is at its maximum.

In general, the higher the average daily sunshine the greater the potential yield. Given no other limiting factors, the indications are that extremes between 1,000 hrs/y (or 2.7 hr/day) and 2,250 h/yr would give potential yields between 17.6 and 30 t/ha respectively. The effect of sunshine on yield would be better expressed in terms of radiation received by the palm since overcast skies can still result in significant radiation being received. Table 2 illustrates the effect of sunshine hours on yield expectation, in combination with variable moisture and soil conditions.

Table 2. Yield expectations as a function of variations in soil types, sunshine hours and moisture deficits (Ochs, 1977).

4.2 Soil Requirements

Oil palm can be grown on a wide range of soils. Soil physical properties, and soil moisture in particular, are more important than nutrient supply, which can anyhow be corrected by fertilizer application. The crop should be planted, wherever possible, on flat or undulating land: steep slopes increase both the risk of erosion and the cost of establishment and production, including the more difficult and more costly construction of access roads.

Soil physical characteristics – Oil palm requires deep and easily penetrable soils with a good moisture retention and free drainage. The primary taproot descends deeply from the base of the trunk, but remains short when the water table is high. Most finer secondary roots are in the top 1m of soil. The crop supports water logging only for short periods.

In general, plantation managers distinguish four types of soils (Table 2):

- I = Well structured soils, with 15-35% clay content and unrestricted rooting volume;
- II = Deep sandy (loam) soils with limited water holding capacity;
- III = Moderately deep soils, with variable texture, but slightly impeded by dispersed gravel, or shallow soils and/or rapid run-off;
- IV = Soils with variable texture, but with rooting restricted to less than 1m by a hard pan or very high water table.

Soil chemical and nutrient characteristics – Oil palm establishes fairly well on relatively poor soils, though the fertility level in the root zone always affects yield. In chemically poor soils the crop is sensitive to the equilibrium between the various elements. Hence, the C/N ratio should be near 10 on the soil surface; exchangeable K^+ should be at least 0.15 - 0.20 me/100g soil; available P should be at least 3 - 5 mg/kg soil; Mg/K and Ca/K should be above 2; and pH should be higher than 4.5. Generally, in the immature stage of a new plantation, fertilizer requirements are assessed by reference to soil analyses; thereafter foliar analyses are used. More details on fertilizing practices are discussed in the chapter on Crop and Land Husbandry.

The amount of nutrients removed from an oil palm grove is nevertheless greater than for most other tropical plantation crops. A drop in the nutrient soil reserves after harvest may, if not replenished, result in growth and yield reductions. Table 3 gives an estimation of the nutrient quantities exported by the crop at various yield levels.

Table 3. Nutrients removed per ha by Tenera at different yields (kg/ha).

5. Land and Crop Husbandry

Oil palm is mainly an industrial estate crop. This means that it occupies a large area of 3,000 to 5,000ha around a central oil mill, where the harvested fresh fruit bunches (FFB) are collected and processed immediately; if this procedure is not properly followed the oil quality deteriorates rapidly. The crop can, however, also be grown by smallholders, either in village gardens (for local consumption) or in plots of 2 to 3ha (for semi-industrial oil production); in the latter cases the oil quality is much lower and does generally not meet the quality standards for commercialization.

Smallholders' oil palm groves are usually intercropped during the first years with food crops in order to provide also some food and cash crops while awaiting the income from the oil. Soybeans, cassava, maize and pineapple are some of the crops used in inter-planting. Because smallholders' plantations receive less agrochemical treatments, they are more easily affected by pests and diseases and have lower yields.

Over the past 25-30 years there is a general tendency to combine large-scale industrial plantations with smallholders' plots, whereby the latter receive technical and agrochemical support from the industrial unit and, in return, supply fresh fruits to the central treatment unit. Obviously, the end product of these smallholders plantations approaches the quality standards of the industrial oil mills.

5.1 Land Clearing

The objective of land clearing is to convert the existing vegetative stand into an area which is suitable for oil palm planting. This requires that the initial vegetative cover be eliminated and the soil be made free of pests, diseases and other hazards which hamper crop production and access to the land. Initially, most land clearing for oil palm groves was made from jungle land. More recently new estates are established from the conversion of land that was formerly cropped by rubber, coconut, oil palm itself or by any other form of cultivation.

Clearing from jungle land - This was until some 10-15 years ago the most common form for the creation of new oil palm estates. It requires the evacuation of a high amount of vegetative matter and a strict time schedule to be followed, as this is a long-time undertaking whereby a number of operations are linked to the start and length of the wet and dry season. If, as was the case in the past, most of the clearing had to be done by hand, much local labor has to be hired as well. With the present-day mechanical clearing, the total time of operations can be estimated at 8-12 months for an average estate of 3,000 to 5,000ha.

A standard land clearing operation starting from a dense jungle involves 5 consecutive steps: land drainage, under-brushing and felling of trees, burn and evacuation of disposal, pruning, stacking into windrows and re-burning, clearing timber from the inter-row paths, and soil preparation. In practice, this means that a preliminary control of the drainage pattern is made to facilitate access and operational mobility of heavy machinery, and that afterwards all vegetative cover is eliminated starting with the undergrowth and ending with the abatement and uprooting of the larger trees, their heaping into windrows, and burning.

The amount of work involved in felling, nowadays carried out by bulldozers or tractors fitted with a front-mounted tree-dozer and by gangs using chain-saws (formerly axes), is determined by previous logging operations and the density of the remaining stand of non-commercial timber. For large trees with a diameter of more than 1.5m cutting is started at the point where the buttress roots arise from the trunk. After felling, the trees can either be pushed into windrows, or first cut into 3-4 sections for easier stacking. In this standard procedure the burning of all vegetative disposal is a key component because it is a means to control pathological pests and diseases, and facilitates access for later planting and maintenance operations. Since the mid 1990s there is, however, a major concern about the environmental consequences of such burning, and alternative procedures have been proposed, with the final objective to end up with a zero burning technique.

The zero burning technique involves the felling of all trees and shredding the trunk tissues into 5-10 cm thick pieces to accelerate the decomposition of plant tissues. The method offers a number of advantages, including the absence of air pollution and a better recycling of organic matter and nutrients, but does not solve the risk for pests and diseases. It must therefore be complemented by an intensive insecticide treatment and a subsequent manual control of *Oryctes* larvae, in particular. The rapid development of a cover plant on both the soil surface and the decaying larger tree trunks seems to reduce the rapid expansion of most infestations, and is therefore often associated with modern zero burning techniques.

Alternative land clearing techniques – Currently, there are three main techniques for land clearing in operation. The *first method* corresponds to the traditional agricultural practice, still widely used by small-holders, whereby burning is maintained because it is considered an easy tool to clean the land, an efficient phyto-sanitary measure against pests, and a natural fertilizer. Burning the land in the dry period has moreover an important social function as it allows for hunting and collection of bush meat at a moment most of the traditional food stocks are at a low level.

The ashes collected after burning are directly used by the newly planted palms and serve as a good nutrient base for inter-row crops like maize, cassava or vegetables. If no inter-row cropping is performed the space is occupied by a rapidly growing cover crop (see below).

The *second method* applies the zero burning principle and is almost exclusively applied in large modern oil palm estates, in particular in Malaysia. It is based on the general acceptance that soil organic material should be preserved wherever possible, but that an adequate solution be found against the infestation of pests and diseases, in particular *Oryctes* and *Coelaenomenodera spp.* A strict (manual) sanitary control of the crop and a prompt removal of the decaying crop residues and felled trees is needed, completed by a frequent and adequate phyto-pharmaceutical treatment with a product that should be preference be non-toxic and easily biodegradable. Unfortunately, chemical treatments need still to make use of Furadan, a highly toxic insecticide (*see also: Land Management*).

The *third alternative* forms a slight modification of the former technique, in the sense that a limited burning of the loose vegetative material is performed in a system with the following steps : (a) chemical treatment of the adventitious weeds by a herbicide spray, followed by a manual uprooting; (b) directional mechanical down-pulling of the old trees by a bulldozer; (c) accumulation of vegetative matter into lined windrows; (d) manual cleaning of the side leaves and branches from the stipe, and burning of this leafy material, and (e) rapid sowing of a *Pueraria* cover crop for complete soil and windrow coverage. The advantage of this method is that, besides avoiding air pollution for a number of days, it facilitates access to the fields, eases planting and maintains the bulk of the organic matter. Moreover, it promotes the rapid development of *Pueraria* due to the better insolation and the extra nutrient supply from the ashes. This method seems to be the best adapted to land clearing of previously cropped fields.

Clearing from former rubber plantations – Here, land clearing can be carried out much quicker and at lower costs. Use of rubber trunks for wood is also beneficial and gives an additional financial return. It is preferable to uproot the older rubber stumps, since leaving them in the soil is a potential hazard for *Oryctes* beetles which use them as excellent breeding grounds. As a general rule, there is a negligible disease risk for oil palm from rubber stumps, although some loss can occur in young palms when these are planted in areas where the rubber suffered severely from root disease caused by *Phellinus (Fomex) noxius*.

Clearing from coconut plantations – Much of the technique of clearing coconut land for oil palm planting is related to the necessity for avoiding later damage by *Oryctes* beetles and *Ganoderma* infections. The beetles are almost invariably present in coconuts, both in dead standing trunks and in stumps after felling, and young oil palms can suffer severe setbacks through repeated beetle attacks. Far more lethal is the infection by *Ganoderma* which arises through root contact by the young stand with coconut stumps colonized by the pathogen.

After clearing the land, it is usual to plow the area before proceeding with other field operations. A sequence of cross plowing and tine harrowing is used for two main reasons. The first is to alleviate any soil compaction which may have resulted from using bulldozers, especially on heavy soils. The second is to break up the remaining root masses and bring to the surface any large blocks of tissue driven underground during the clearing operations and which could possibly become disease foci.

Clearing from former oil palm areas – With the tendency to reduce the age at which the oil palm stand is replaced by newer and higher-yielding material, this form of clearing becomes more and more frequent.

To offset loss of revenue during the immature period of the young stand, older palms are sometimes inter-planted, and the old stand progressively poisoned; the old trees are then either felled or left to rot in situ. This procedure is not recommended because the young palms are adversely affected through competition for light and nutrients by the older trees, whilst at the same time the incidence for transmission of pests and diseases remains high.

A much better method for replanting is to operate first a clean clearing. If the stand is not to be burned the old palms are first poisoned to accelerate later decomposition. Trees can then be pushed over, cut into short lengths, dragged to stacking parts, and collected in windrows for burning, or eliminated as disposal from the fields. Aligning the felled palms into windrows where the rotting process is accelerated has the advantage that the manual eradication of *Oryctes* pests in this concentrated location is facilitated.

Clearing from *Imperata cylindrica* – *Imperata* is a persistent weed which is highly competitive with oil palm and other perennial crops. It develops a widespread system of underground rhizomes, which make it expensive to eradicate. Clearing an area from *Imperata* is not really difficult, but it must be carried out thoroughly before palm planting and the importance of subsequently keeping the area *Imperata*-free through regular maintenance is considerable.

Imperata can be eradicated by mechanical means, i.e. plowing and harrowing, or by chemical treatment using a systemic herbicide. The most frequently used herbicide is dalapan, which is available in a number of commercial formulations, and has the advantage in persisting in the soil for a very short time. The operations, both mechanical and chemical, need to be repeated several times before the weed is more or less completely controlled.

5.2 Planting and Land Management

Field Lay-Out and Plant Density - Field size corresponds usually with blocs of 100ha, separated by one main N-S oriented road and 4 intermediate E-W roads every 250m. The accepted norms for the road network are : 20m of 8-meter wide link roads (asphalted tracks) and 40m of 5-meter wide collection paths per hectare of plantation. The field lay-out should mainly be carried out in the dry season. It should also take into account that FFB bunches should not be carried more than 200m to the road where they are picked up for further transport.

The plant population density is targeted at 143 trees/ha, but because of possible losses a minimum of 120 palms is needed. Optimal results are obtained by a triangular (9 by 9m, and 7.80m between the lines) or square (at 9m spacing) planting patterns. Yields diminish rapidly with higher density due to increased competition for light, water and nutrients. Plantation managers are very keen to maintain the target density and pay therefore extreme attention to cure their young plants and protect them against diseases and pests. Replanting is risky due to the rapid development of the plant canopy of neighboring trees and the reduced sunshine left for the new seedlings. Moreover, a loss of production of a few trees over the total lifetime of the plantation presents an important financial gap.

Planting should by preference be done in the beginning of the rainy season. Young plants are in a first phase grown up in a nursery. To provide plant material for a 500ha plantation, a 5ha nursery must be set up. Transplants in the field should be 12-18 months old. Planting holes should be 0.5m x 0.5m and approximately 50-70cm deep. Holes should be supplied with KCl, kieserite or magnesium sulfate; fitting a wire collar protection (or putting a poisoned bait) is often recommended against rodents.

Around the new plantings a circular area of about 1,5-2m around the tree base should be kept clean. This takes 6 weeding rounds/year during the palms immature years, and 3 rounds/year thereafter. In addition, inter-rows are mowed 2-3 times per years.

Cover Crop - Once established in the field the space between the trees is rapidly occupied by a cover crop, either *Calopogonium*, *Centrosema*, *Pueraria* or *Mucuna bracteata*. All of these have the advantage that they rapidly establish and thus protect the surface, provide a high amount of organic material to the soil, avoid weed development, and serve as a nitrogen supplier to the crop. *Oryctes* do not develop easily in this environment.

Fertilizers - The exact amount of fertilizers to be supplied depends in the first place on the nutrient status of the soil before planting. Nitrogen dressings are important in the early years and are usually in the order of 0.22kg N per palm in the planting year, and 0.45kg per year for the following 3-4 years. Phosphate deficiency is rare.

Potassium requirements are high, because large quantities of K are removed in the fruit bunches (Table 2). Where old plantations become deficient in K, dressings up to 4.5kg KCl per tree over several years may be needed for full responses. In areas recently opened from dense forest, applications of 2.5-3kg of potassium sulfate applied every third year may be sufficient. Mg deficiency is common, particularly on former rubber land. Heavy K fertilization inhibits the uptake of Mg, and therefore requires a control of the Mg/K balance. To counteract a possible imbalance in young palms, dressings of 0.1, 0.2 and 0.4 kg anhydrous magnesium sulfate in the first, second and third years are recommended. Kieserite or magnesium limestone is sometimes applied as well.

Boron is the most common deficient micronutrient in oil palm groves; this can be remediated by an additional borax dressing. Copper deficiency (mid crown chlorosis) is found in Asian peat soils and in very poor “campo cerrado” soils in Brazil. Zinc deficiency (reflected in a general yellowing and stunting of the palm) often goes together with copper deficiencies. Iron, manganese and molybdenum are not likely to cause problems; the first two are also antagonistic.

5.3 Pests and Diseases

Oil palm is very sensitive to pests and diseases, from the nursery stage to the trees in full production. Pest and disease control in an oil palm estate is therefore as important as the care and management for vegetative growth and production. In poorly controlled infected plantations yield losses can be as high as 50% or more as compared to the potential yields.

The most important diseases are: blast, freckle, anthracnose, seedling blight, crown disease, *Fusarium oxysporum* and basal trunk rot. Main pests include: palm weevil, leaf miners, slug caterpillar and the red ring nematode; many of these pests attack also coconut trees. Some of these are mainly observed in the nursery, while others are associated with open field conditions.

5.3.1 Nursery Deficiency Diseases

These are often the result of a nutrient disorder in the seedling nutrition. They refer in particular to nitrogen, magnesium and boron deficiencies, whether or not linked to a general nutrient imbalance.

Nitrogen deficiency creates a nutrient disorder which is at the origin of reduced growth and the development of pale green and yellow leaf colors. It is readily remediated by applying a nitrogen foliar spray. Magnesium deficiency occurs in substrata which are poor in this element, as for example peat, and affects the seedlings by a discoloration of older leaves, preceded by a loss of the normal glossy appearance. Remediation is done by the application of kieserite (magnesium sulfate).

Boron deficiency is suspected to be at the origin of a pendulous fiber between the leaves and transverse corrugated bands across the leaf; It is corrected by a spray of 0.5% borax.

5.3.2 Nursery Pests

Though the number of pests in oil palm nurseries is generally small they can result in total loss or destruction of the seedling tissues, or at least in a reduced vegetative development and vigor, so that affected seedlings are retarded, with long-term effects on early yield.

There are many insects which may feed on oil palm seedlings, but comparatively few pose serious pest problems. The most frequently encountered pests are:

- mealybugs (*Planococcus citri*): They are usually brought inside the nursery by ants. They live in colonies on the unexposed parts of the leaves, basically below the collar, and damage roots or retard seedling development. Organophosphates such as dimethoate or parathion, have a marked action on these parasites;
- weevils (*Temnoschoita spp.*) are responsible for necrosis of the central leaf. Tearing out the leaf reveals a heart rot and small, white, brown-headed apodal larvae or small cocoons of fibers. Repeated spraying (2-3 times) with dimethoate may prove necessary, but an aldicarb treatment usually suffices;
- red spider mites, including *Oligonychus* and *Tetranychus spp.*: They can be very active during prolonged dry weather; some of them are so small that they can only be detected by a hand lens;
- other pests of minor or only local importance in nurseries are : ants, aphids, crickets and grasshoppers, cockchafers, caterpillars, slugs, snails and rats.

5.3.3 Nursery Diseases

The outbreak of nursery diseases is often an indication of sub-optimal nursery management. The decline in disease levels has been almost entirely attributed to the improvement in nursery techniques, and in particular to the introduction of the polybags and the virtual absence of transplanting shock, which is a feature of it. Together with the attention to bag filling with a good soil type, a balanced fertilizer schedule, and sufficient water supply for optimal growth, a stage has been reached when strong healthy seedlings are the norm.

The following is a list of major diseases encountered in oil palm nurseries in the Far East and Africa:

- freckle, caused by the fungus *Cercospora elaeidis*, creates orange-brown speckles on the older leaves, culminating in the drying out of leaf tips and edges; it occurs mainly in the middle and at the end of the dry season;
- blast disease, apparently associated to poor water management in the polybags. It was for a long time believed that the disease was caused by the combined attack of two fungi: *Pythiom* and *Rhizoctonia*, but recent studies have shown that the disease is transmitted by an insect of the family Jassidae, *Recilia mica*, that feeds primarily on grasses. Shading the nursery has been shown to be very effective against blast. Currently, nurseries are being protected by monthly applications of the systemic insecticide aldicarb. Clean-weeding the entire nursery and the surrounding area is advised to prevent the spread of *R. mica*.
- Other leaf diseases of minor incidence are: early leaf disease (or *anthracnose*), caused by a variety of fungi including *Glomerella cingulata*, *Botryodiplodia spp.* and *Melanconium elaeidis*; *Corticium* leaf rot, apparently to be related to high rainfall and poor soil drainage conditions; *Curvularia* seedling blight, rather common in the Far East, and probably caused

by a nutrient imbalance in the plant; *Helminthosporium* leaf spot, nursery spear rot, *Leptosphaeria* leaf spot, etc.

Nursery leaf diseases can be controlled and/or treated by sanitation methods, fungicide sprays, or prophylactic sprays. However, as many of the formerly used phyto-pharmaceutical products are ecotoxic, there is a tendency to ban those and replace them, wherever possible, by less toxic products. Research is going on to replace the most toxic chemical products by less toxic variants.

5.3.4 Field Pests

Pests affecting oil palm trees can fall into four groups: vertebrates comprising mammals and birds; arthropods, especially insects and mites; mollusks, slugs and snails; and nematodes.

Rats are one of the most serious pests of oil palm at all stages of development; their population may overpass more than 1,000 per ha; snakes are their natural predator. Rats create most damage to the pericarp of the mature fruits or inflorescences, whereby the wounded palms become prime targets for insect oviposition and fungal growth. As rats can never be eradicated completely, the objective is mainly to control their number. In new plantings the young trees can be protected by a 25cm high and 50cm long wire guard with a mesh size of 1-1.5cm. The common way to trap the animals is by poison baiting, whereby a poison is mixed with attractive substances for them to take.

Porcupines – Losses by porcupines are serious in isolated estates or fields and along boundaries with the jungle. Porcupines are nocturnal feeders; they operate scattered or in groups. The most frequently encountered species are *Hystrix brachyuran*, *Thecarus crassispinis* and *Trichys lipura*. In much the same way as rats, porcupines chew through the frond base to reach the tender stem tissues; the extent of the damage is, however, greater than with rats. Occasionally, young palms may also be dragged away before they are eaten. It has been noted that porcupines often attack the same palms on successive nights. They can be fought by smoking out their nests, shooting or by using baits and traps close to the boundary of the fields.

Cutting grass (*Thryonomus swinderianus*) is a rodent living in nearly jungle and shrubs, mainly in West Africa. It causes damages similar to those from rats and porcupines, but attacks only young plantings, maximum 3 years old. *Squirrels* attack mainly ripe fruits on trees located nearly jungle boundaries; they are particularly active in the early morning and early evening. The damage created by *monkeys* is mainly in uprooting young seedlings without apparent reason. No effective control measure is yet devised; shooting on or two animals seems however to discourage the others to attack.

Birds – There are a number of birds which eat mature oil palm fruits; occasionally, immature fruit is also attacked. They include parakeets, lorikeets and parrots (Asia) or vultures (South America and Africa). In West Africa, weaver birds use palm pinnae for nest construction.

Nematodes – They develop on rotting tissues. The nematode causing serious economic loss to oil palm is *Rhadinaphelenchus cocophilus*, the causal agent of red ring disease, and carried by the palm weevil *Rhyncophorus palmarum*. Because of this disease the supply of water and nutrients to the crown is impeded, leaves are malformed, and the foliage dries out; fruit set does not occur and any developing bunches abort.

Ants and termites – There are several types of ants in palm plantations. Most ants cause little harm, except leaf-cutting ants which cut laminar tissues for the construction of their subterranean nests. Termites are most damaging in palms planted in peat soils. The termites tunnel through the palm,

preferring to attack the upper stem tissues. Ultimately, the trunk is so weakened that it collapses. Palms killed by termites should be evacuated from the grove.

Beetles – This group of animals can cause damage of very serious economic proportions. The beetles as a group are made up of leaf miners, weevils, cockchafers and larger dynastid beetles. Some of them, like the rhinoceros beetle are common pests to both oil palm and coconuts.

Leaf miners cause defoliation. Typically, the damage is caused by the larvae burrowing beneath the upper epidermis of the pinnae, usually of palms over 3 years old in the field, and feed on the mesophyll tissues so that the pinnae are hollowed out. The contamination spreads, from an initial focus, from tree to tree and may infest an entire plantation if not checked. In the Far East the most common leaf miner is *Promecotheca cumingi*; in Africa it is *Coelaenomenodera elaedis*; in South America it is *Hispoleptis elaedis* and *Alurnus humeralis*.

Weevils – Damage by various weevil species arises after penetration of surfaces first affected by rodents, or after burrowing through the cut ends of frond butts after pruning. Many species of weevil are attracted by the odor and exudates of exposed tissues. Species of *Rhyncophorus* occur in almost all oil palm areas. Their control is difficult and estate sanitation has been widely recommended, with removal and destruction of dead palms.

Cockchafers – Damage by cockchafers can focus on the foliage by leaf-eating pests (*Apogonia* and *Adoretus*) or on the roots by cockchafer larvae (*Psilopholis vestita*); the latter pest leads to reductions in both growth and yield.

Rhinoceros beetles – This is one of the most serious pests of oil palm. Primarily a pest of coconuts, the beetle attacks palms at all ages but its effects are more serious when young palms are attacked soon after planting. The most frequently encountered species is *Oryctes rhinoceros*, both in the Far East and in Africa.

The females of *Oryctes sp.* and *Augosoma sp.* (Scarabaeidae) lay their eggs in soft decomposing wood, especially on old palm stipes; infestation is common after replanting. The damage caused by the adults of the *Oryctes sp.* as they move about at nightfall consists of galleries of up to 1m long burrowed in the unopened leaves and extending down to the collar. The infested leaves exhibit very characteristic indentations in a herring-bone pattern. *Augosoma sp.* usually breed in very humid areas, often populated with *Raphia* palms, and cause similar but more severe damage given their larger size. Infested plants are killed or seriously damaged. Systematic surveillance must be organized as soon as any adults are spotted. A variety of control methods are used, including catching the adults in light or chemical (ethyl chrysanthemate) traps, and coating or dusting infested plants with gamma-HCH.

Oil palm bunch pests – These occur through attacks by the caterpillar stage of the oil palm bunch mot, *Thirathaba mundella*. Treatment is achieved by insecticide sprays.

5.3.5 Field Diseases

Although over 400 different fungi have been recorded in association with oil palm and its products, diseases associated with pathogens are of comparatively little economic significance. There are different types of diseases: leaf diseases, fruit bunch diseases, trunk and root diseases.

Leaf diseases – Most diseases of any economic significance affecting the foliage are associated, at least in the initial stages, with the rotting of the unexpanded fronds while they are still in the spear stage. Tissues during this phase are much softer than they are at maturity. The humid conditions

deep within the crown appear to be ideal for rapid fungal development and spread once infection has occurred.

Crown diseases – These can typically be observed 2-3 years after field planting, though they can also occur in other growth stages. They are rarely lethal but retard development, with consequent yield reduction. Precise causes have never been determined, but there is evidence that susceptibility to the disease is genetically controlled.

Spear and bud rot – Patch yellow diseases are mainly confined to Africa, and are caused by a fungus (*Fusarium oxysporum*); its equivalent in the Far East and South America is the Whiter Tip disease. As trees affected by these diseases compete for light, moisture and nutrients with neighboring bearing palms, it is sometimes recommended to poison and excavate them.

Causes for these diseases seem to be complex and rather ill-defined. In the Far East, the disease in most instances is related to a primary attack by the rhinoceros beetle, *Oryctes rhinoceros*, with secondary destruction of spear and bud tissues by fungi and bacteria. In the Congo, a bacterium, *Erwinia lathyri*, has been shown to be pathogenic. Under other circumstances, i.e. South and Central America, poor drainage, flooding and soil compaction have been considered as possible factors.

Crusty leaf spot disease, Pestalotiopsis leaf spot, sooty moulds and genetic orange spotting are other leaf diseases caused by fungi, but with less economic impact.

Marasmius bunch rot – This is by far the most important bunch rot disease; it is caused by the pathogen *Marasmius palmivorus*. White strands of mycelium spread over the bunch surface, permeate between the individual fruits, and penetrate the fruit pericarp, producing a wet rot which is light brown in color and induces a sharp rise in the free fatty acid content.

Fruit rot – This disease is almost invariably associated with over-ripe fruit, a situation in which the tissues rapidly become moribund. In such fruit the mesocarp becomes blackened in color and has a soft, water consistency. Decomposition of the oil and other cell contents occur, whilst the outside becomes covered in the fruit bodies of numerous fungi.

Upper stem rot – The number of pathogens directly invading upper trunk tissues is very small. Of these, only *Phellinus (Fomes) noxius*, causing upper stem rot, is of any significance. The incidence with a primary infection by *Ganoderma spp.* is possible. The disease at this level is of minor economic importance, except where it affects palms used for commercial seed production. The cause of the disease seems to be linked to soil properties (peaty soils, shallow soils, low potassium status, etc.).

Armillaria root and trunk rot – This disease occurs at the base of the trunk and the premature falling away of frond bases up to a height of about 60cm above ground level. The causal pathogen is a fungus, *Armillaria melea*, which is normally an inhabitant of jungle stumps. Rotting tissues are marked by narrow black zonations and are often malodorous. Infected roots are rotten and contain large amounts of white fungal mycelium.

Charcoal base rot, caused by *Ustilina deusta*, **dry basal rot** (*Ceratocystus paradoxa*), **stem wet rot** and **basal stem rot** (*Ganoderma spp.*) are variants of the former root rot diseases with little economic impact, except for the latter which could locally cause yield reductions up to 20%. *Ganoderma lucida* usually attacks old trees only, and its mycelium is frequently seen on old rotting forest stumps. The palm is contaminated by contacts between its roots and such stumps. The brown mycelium penetrates the roots and advances quickly towards the stipe of the palm, where it causes a

crumbly dry rot. Once the palm's bole is colonized, a certain number of mushrooms appear. These at first pad-like sporophores turn into consoles with a chocolate-brown surface and a creamy gray underside. The symptoms of the foliage of *G. lucida* infection are identical to those produced by *A. mellea*. The palm dies *in situ* after necrosis of the central spear. There is no remedy for this disease.

Vascular wilt disease, also known as *fusariose* or *tracheomyose*, has resulted in losses of serious economic significance, mainly in West Africa and the Congo. The causal pathogen is a strain of *Fusarium oxysporum*. Wilting is induced by restricting the supply of water and nutrients to the leaves through blocking the conducting tissue. Infected palms should be removed.

Most pests and diseases could formerly be controlled in a more or less satisfactory way by insecticide spraying. Besides the fact that many insecticides are very toxic, they may also develop long-term imbalances in the naturally-occurring proportions of (potential) pests and their predators. Current developments indicate that the number of (very) toxic agrochemicals used in oil palm estates are nowadays replaced by more environment-friendly measures or products. These trends are enforced by the legislative guidelines imposed by international agencies like WHO, World Bank, IFC or FAO as a prerequisite to allocate development funds to organizations, governments or estates which have banned the use of toxic phyto-pharmaceuticals, even if these are only slowly acting and sometimes less efficient. However, their use is highly recommended from the long-term benefits derived from the relatively minor amount of population imbalance which results from its usage. The reader is referred to the recent literature on the use of agrochemicals for the most recent developments in this relatively recent research domain (*see also: Land Use Management*).

5.4 Crop Forecasting

Crop forecasting is an important element in price setting in world commodity markets, but as a number of decisive yield parameters can be determined several months before harvesting, such a forecasting procedure can be economically interesting.

Oil Production - Short term forecasting over 6 months is based on the principle that it takes a bunch 5-6 months to ripen. Thus, the production for 6 months is visible on the palms. A bunch count on 1% of the palms (every tenth palm in every tenth row) and the average bunch weight provides an excellent yield forecasting measure for the next 6 months. Short term sales contracts of palm oil and palm kernel can be made based on this information.

Oil Extraction Rate - Forecasting the oil extraction from the fresh fruit bunch can be achieved on the basis of the knowledge that only during the last 4 weeks of bunch development the oil is formed in the pulp (mesocarp) around the nut. The percentage oil to fresh mesocarp is mostly determined genetically, but solar radiation during this final ripening period has a sharp effect on the oil/mesocarp percentage. In this respect a very high correlation could be found between the factory extraction rate and the total radiation 5 weeks earlier. The only limitation to this approach is that the prediction works only satisfactorily for periods with no water stress.

Abortion Rate – About 5 months before an inflorescence sheds pollen or is pollinated, it elongates rapidly and is then very sensitive to abortion, especially under drought stress. This becomes only visible 5 months later because there is no inflorescence in the leaf axil, and thus no bunch to be harvested at harvest time 5-6 months later. Hence, there is a time lag of approximately 11 months between abortion and harvest. By controlling the moisture status of the palm grove some 11 months before harvest and applying an irrigation the adverse effect of a possible abortion can be avoided.

5.5 Harvesting

A fresh fruit bunch (FFB) weights on average 20-30kg depending on the age of the tree. Oil content of fruit pulp is 50-60% or 20-22% of the bunch weight. Oil content of kernels is 48-52% of the kernel weight, or 2-2.5% of the bunch weight. Under optimal conditions yields may reach 25-30 t FFB/ha/y, and with an average extraction rate of 21-23% this corresponds with an approximate yield of 6 tons of oil per hectare. Under sub-optimal conditions the average yield drops to 4-5 tons of oil per hectare.

The first 3-4 years, the production of the young palms is often small, of poor quality, and sometimes even not economic to be harvested. Full production starts from the 6th year onwards; it reaches its maximum 4 to 6 years later, and remains high for another 10 years. It begins to decline when the trees are 20-22 years old. In industrial plantations trees are cut and replaced after approximately 25 to 30 years, both because at that moment the production decreases and the trees become so tall that harvesting is difficult. Fruit bunches are harvested by hand (machete), usually once every fortnight, and brought to the border of the road in a collection point, from where they are transported by truck to the oil mill (Figure 5). A man can harvest 100-150 bunches per day, provided the palms are not very tall and that he is assisted by somebody who carries the bunches to the field collection points.

Figure 5. Harvested oil palm bunches at a collection point to be transported to the oil mill; the bunches of each harvester are identified and the dropped fruits are collected separately (Courtesy D. De Waele).

Time of harvesting is very critical: premature harvesting results in a reduced weight, whereas delayed harvesting may result in lower quality because of an elevated free fatty acid (FFA) content. After harvesting, the fruit bunches should be handled carefully and processed as soon as possible in order to keep the FFA level low. When organized on a piece-work basis the harvest of 1 ton of fresh fruit bunches (FFB) requires 3-5 man-days depending on the production level on the estate. Except for land clearing, oil palm farming does not lend itself very much to mechanization.

6. Milling and Oil Processing

The purpose of milling the palm fruit or, more precisely the fruit + stalks, is to extract the oil from the pulp and separate the palm kernel from the rest. Palm oil from the fruits pulp is extracted mechanically by pressing. In contrast, palm kernel oil is extracted chemically by a solvent, like the subsequent refining operations. For this reason, only the major producer countries have such facilities. The description of the oil processing in industrial plants and in traditional oil mills is taken from Cornet (2001).

On *industrial sites*, the pre-treatment operations consist of taking delivery of the bunches at the factory and weighing them on the weighbridge, placing them on the unloading platform and loading the sterilization cages. The treatment itself consists of a series of operations. The goal of steam sterilization is to strip the fruits more easily, to disinfect them by killing any pathogenic microbes and rendering the lipolytic enzymes inactive so as to prevent the formation of free fatty acids. Stripping separates the fruits from the stalks.

The next step is to mix and crush the fruit to produce a hot, homogeneous pulp. It is used to separate the pericarp from the palm nut and crushes mesocarp's oil producing cells fairly well. The temperature inside the mixer (a cylindrical vessel with a central, vertically mounted, rotary shaft), is kept at 95° C. The pulp is pressed in a screw press, a hydraulic press or a centrifugal press. The mixing and pressing constitute the oil extraction proper. The crude oil is clarified in the settling tank. The aim of this is to separate the oil from the water, dissolved sugars, salts and cell compounds originating from the mesocarp; the pure oil is skimmed off the surface while any

impurities sink to the bottom. The clarified oil is then dehydrated to lower its water content to 0.1-0.2% for better and thus stronger storage.

After pressing, the oil palm seeds are stripped from their fibers and dried. The kernels are separated from the shells by crushing. This part of the factory is called the crushing unit. The shells and fibers are burned in steam boilers and the kernels are bagged for export and/or chemical extraction of the palm kernel oil.

It is important to know that modern, industrial-scale oil mills (capacity 5-20 t/hr) are self-sufficient energy-wise, meeting their energy needs by burning the fibers and shells in their boilers. In smaller installations or factories with less efficient boiling, mixing and pressing technology, additional energy must be supplied by wood, charcoal, fuel or electricity.

Traditionally, palm oil is extracted by hand, except for the pressing, which is performed by a screw press or a hydraulic press in the artisanal process. The methods vary greatly, depending on the region, dietary habits and end use of the oil, but basically consist in quartering the bunches, followed (immediately or after 2 to 4 days) by detaching the fruits, heating them in water, crushing and pressing them (by hand, a hand press or a motorized press), collecting the crude oil and clarifying it by prolonged boiling followed by settling. After a second skimming, the clarified oil may be boiled again to expel as much water as possible.

This long, laborious process yields a poor quality oil, according to prevailing international standards, but one that is often more valued by the local population than industrial oil. Similarly, the extraction rate is lower than in the industrial process, the oil content varying from 10 to 18% by bunch weight, depending on the type of press that is used. The only mechanized elements in this type of extraction – mainly the presses – are manufactured locally or in the region while the motors are imported. The energy source is generally wood.

7. Utilization and Use

Oil palm gives the highest yield of oil per unit area of any crop and is, worldwide, a major supplier of vegetable oil. Since 2005-2006 it has exceeded soybean production, the long-time industry leader. Oil palm gives 5 to 7 times more oil per ha than other traditional oil crops like groundnuts or soybeans. It is used in food production and in industrial applications.

Yields from commercial oil palm estates differ from those obtained by smallholders. Average yields on industrial plantations range from 12 to 18 tons FFB/ha/year, with a yield potential of 18 to 22 tons. Higher *ad hoc* yields, in the order of 22 or more tons FFB/ha/year can sometimes be achieved on the better plantations. It is considered that for yields below 8-10 tons the profitability of the oil mill is at risk. In terms of palm oil extraction, the above figures correspond to 4 to 6 tons palm oil/ha, plus 0.5 to 1 ton kernels (50% oil) annually/ha. Comparatively, smallholders obtain from 300 to 800 kg of oil/ha.

Palm trees produce two distinct vegetable oils, palm oil and palm kernel oil, both of which are important in world trade. Other mainly local uses include: palm wine from the tree sap, leaves for thatching, soap production. Empty fruit bunches are used as soil manure and amendment (see above).

Palm oil is obtained from the fleshy mesocarp of the fruit, which contains 50-60% oil. The oil melts over a range of temperatures up to 50° C. It is light yellow to orange red in color, the depth of color depending on the amount of carotene present, the amount of oxidation by lipoxidases before

processing, and oxidation catalyzed by iron during processing and bulking. For edible fat manufacture the oil must be bleached.

Palm oil contains a high proportion of saturated palmitic acid, as well as considerable quantities of oleic and linoleic acids which give it a higher unsaturated acid content than coconut and palm kernel oils. Poorly prepared palm oil has a high free fatty acid content and renders it unsuitable for edible purposes in importing countries and, therefore, requires additional treatment before proper commercialization; for this reason palm oil has for long time been considered a low-value edible oil, though in recent years this perception is gradually improving. Palm oil was widely used in the manufacture of soap and candles, but this use tends to decline. With the improvement in quality it is being increasingly used for edible purposes, including the manufacture of margarine and composed cooking fats.

Palm kernel oil is obtained from the kernel or endosperm which contains about 50% oil, the shell or endocarp having been removed. It is a hard oil, closely resembling coconut oil with which it is readily interchangeable. It has a high proportion of saturated, predominantly lauric acids. It is solid at ambient temperatures in temperate countries, and is nearly colorless. It is used in edible fats, in the confectionary and bakery trades, in the preparation of ice-cream and mayonnaise, and in the manufacture of toilet soaps, soap powders and detergents. The press cake, after the extraction of oil from the kernels, is an important livestock feed.

Palm wine is produced from the sap obtained by tapping the male inflorescence, after incising it once or twice a day and exuding the sap that is funneled by a piece of bamboo into a calabash or bottle. The fresh sap is sweet and contains about 40g per liter of sucrose and 30g/ liter of glucose, but it ferments quickly by the action of bacteria and naturally yeasts into a milky palm wine with a slight sulfurous odor. It is produced in considerable quantity and is estimated in some parts of Africa to have more than double the value of the oil and kernels. Palm wine can be further distilled into a local brandy.

In recent years there is a tendency to grow oil palm for the production of ***biodiesel***, in Indonesia and Malaysia in particular. In the last few years, oil palm has been considered a serious source for biodiesel. Initially, the Malaysian Government had approved 20 biodiesel projects since early 2006, mainly with overseas investments amounting \$515 million. At first, the Malaysian Government appeared to welcome biodiesel as an alternative outlet to its oil palm production and a potential vehicle for future economic growth. However, when it became apparent that this excessive demand for biodiesel was disturbing the complete oil palm market, the Cabinet suspended the agreements, mainly because it was afraid of the environmental implications and the pressure to open more estates from virgin forest land (Murphy, 2007).

8. Production and Trade

Today Malaysia and Indonesia are by far the biggest producers and exporters of both palm oil and palm kernel oil (Table 4). Papua New Guinea has doubled its production of palm oil over the past 10 years. The Netherlands, Germany and Singapore are trading countries through import of raw materials and export of both raw and processed goods. Ivory Coast has for long time been the most important producer in Africa but due to political turmoil and an adverse rainfall pattern the production has gradually declined.

A new oil palm industry is developing in Latin America: Brazil, Colombia, Costa Rica, Ecuador, Honduras, Guatemala, Nicaragua, Panama, South Mexico and Venezuela, but their production figures are still too low to figure in world production tables.

The UK has for a long time been the largest importer of oil palm products, importing in the 1960s some 180,000 tons of palm oil and 243,000 tons of palm kernels per annum. Now, it has dropped to the fifth rank behind India, China and Pakistan for palm oil, and Germany, USA and China for palm kernel oil.

Table 4. Trade, export and import of palm oil and palm kernel oil in the world
(Source: FAO Statistical Yearbooks).

9. Future Perspectives for Oil Palm Production

Oil palm production is currently at a historic crossroads in terms of production potentials and users' demands. Oil palm has now become the world's leading commercial source of vegetable oil, exceeding now soybean oil, the long-time industry leader. Annual production of palm oil in 2006 was in excess of 38 million tons (in 2003 only 20 million tons, Table 4)), with Indonesia and Malaysia as the major exporters and China, India and the European Union as the principal importers. Palm oil demands at world level are moreover steadily increasing, and as oil palm is a tropical forest crop the extension of plantations is generally at the expense of native forest land. The first challenge deals with production problems to meet increasing user's demands, the second with an environmental problem.

The market demand for palm oil consumption is gradually increasing in the world, and there are three main factors at the origin of this problem: an increased number of consumers, changing dietary customs and the potential for a wider range of uses due mainly to a better fatty acid profile.

Population increase - The first factor is the world's population increase, reflected by the figures of the expanding populations of India and China; the two countries make nowadays already 2.4 billion people, or 37% of the world population. Besides the impact of the number of consumers, there is also a link with the rapidly improving standards of living and dietary customs, which result in a growing demand for vegetable oil.

Dietary habits - There appears to be a relation between living standards and dietary habits. Hence, following rising income levels across much of the developing world in the 1990s vegetable oil and dietary fats consumption increased much faster than general food consumption. The reason for this phenomenon can be explained as follows: people on a starch and vegetable based subsistence diet are faced with relatively dull and tasteless foodstuffs, such as boiled rice, cassava or potatoes. With the addition of fats or oils, flavor, nutrient content and caloric value of the food are greatly enhanced and thus a perception of satisfaction and well-being is created.

This means that, as people become more affluent, they switch to a more satisfying diet containing much higher amounts of oil. Interestingly, the reverse is also true and when times are hard, people tend to cut back on "luxuries" like fats and oils. Such an effects was seen during the economic collapse that followed the fall of the Soviet Union, between 1990 and 1994, consumption of food oil in Russia fell by 35%. Over the next decade, therefore, one can confidently expect a continued demand from Asia (and to a lesser extend from Africa and Latin America) for increasing outputs of commodity-grade vegetable oils, i.e. a market that is particularly favorable for oil palm (Murphy, 2007).

Oil quality improvement – Until recently palm oil had the status of a relatively low value commodity, compared with most seed oils, and the main reason for this perception was the difficulty in manipulating its fatty acid profile. Palm oil has a relatively high content of saturated palmitic acid, as well as a more desirable oleic acid. However, unrefined palm oil is characterized by high levels of nutritionally desirable carotenoids and TOCOLS that give this oil an attractive red

color, and the renewed interest in these antioxidant lipids has been used to upgrade the marketing of red (virgin) palm oil as a high value product in the health food sector.

There are two additional developments that might improve this former negative imago. First, recent studies of oil palm germplasm have shown a much higher genetic diversity in fatty acid profiles than had been hitherto suspected. This opens perspectives for the development of new varieties of oil palm, including high-oleate genotypes. The second development is the use of trans-genesis to produce “designer” oils from this crop. Although such studies are still at an early stage, prospects for a successful outcome are positive (Murphy, 2007). Palm oil is nowadays already used in high energy sports drinks and infant food.

Crop production - Current yields in average plantations in Malaysia are in the range of 20-25 tons/ha of Fresh Fruit Bunches, corresponding to about 3.5 to 4 tons/ha of oil. These yields can almost be doubled well over 6 tons/ha with improved management, reduction of crop losses from pests and diseases, better harvesting methods, reduced spoilage during transport and storage, and more efficient processing in the mills. Large yield improvements can therefore be realized in existing plantations without recourse to expensive new technologies. In addition, palm oil yields may probably even be increased further by using existing high-yield germplasm and/or using advanced screening methods, like DNA-marker assisted selection and/or transgenic technology. If such production levels can be attended, the use of palm oil for both edible and non-edible purposes can be widely extended.

Environmental concern – The pressure on a higher palm oil production is reflected in an increasing demand for the expansion of oil palm estates, in first instance at the expense of virgin jungle land. With the current concern on the worldwide protection of pristine forest land, such expansion will be difficult to achieve. For this reason more and more estates covered by other (less economic) crops are now converted into oil palm estates. Worldwide, newly established estates from former jungle areas are subject to a severe environmental legislation, and are limited very often to less populated areas like in Papua-New Guinea, Indonesia and to a lesser extent Malaysia.

Glossary

- Anthesis:** The time the flower is expanded and is receptive to fertilization.
- Axil:** The upper angle between the leaf and the stem.
- Carotene:** A red or orange-colored compound, found in carrots and some other vegetables, and changed into vitamin A in the body.
- Clone:** A group of plants originating by vegetative propagation from a single plant and therefore of the same genotype.
- Ecozone:** Zone or area with similar ecological characteristics.
- Ecotoxicity:** A poisonous quality or state of the ecosystem.
- Endocarp:** The innermost layer of the pericarp or fruit wall when its texture differs from the outer layer; it may be hard and stony as in plums and peaches, membranous as in apples, and fleshy as in oranges.
- Entomophilous:** Insect-pollinated.
- Evapotranspiration:** A combination of evaporation from a (soil or water) surface and transpiration from a plant.
- Heterozygous:** Having unlike alleles at corresponding loci of homologous chromosomes; an organism can be heterozygous for one or several genes.
- Hybridization:** The crossing of individuals of unlike genetic constitution.
- Hypocotyl:** The part of the axis below the cotyledons in a seedling.
- Inflorescence:** The arrangement and mode of development of the flowers on the floral axis.
- Meristem:** Undifferentiated tissue of the growing point whose cells are capable of dividing and developing into various organs and tissues.
- Mesocarp:** The middle layer of the pericarp or fruit wall which is often fleshy or succulent.
- Mono-ecious:** When the male and female flowers are separate, but borne on the same plant.
- Pericarp:** The wall of the ripened ovary or fruit wall of which the layers may be fused into one, or be more or less divisible into exocarp, mesocarp and endocarp.
- Pinna:** A primary division or leaflet of a pinnate leaf.

- Pollination:** The transfer of pollen from the dehiscent anther to the receptive stigma.
- Polybag:** Bag in polyester material
- Ppm:** Part per million.
- Primordium:** The first recognizable aggregation of cells that will form a distinct organ.
- Rachis:** The principle axis of an inflorescence or a compound leaf.
- Spikelet:** A small indeterminate inflorescence composed of one or more flowers within a common pair of glumes, as in grasses.
- Stipe:** The stalk supporting a carpel or gynoecium; commonly a stem.

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Biographical Sketch

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