Oil Palm – Achievements and Potential

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Abstract
Cultivation of the oil palm (*Elaeis guineensis* Jacq.) has expanded tremendously in recent years such that it is now second only to soybean as a major source of the world supply of oils and fats. Presently, Southeast Asia is the dominant region of production with Malaysia being the leading producer and exporter of palm oil. This paper reviews the various factors that have led to oil palm occupying its present position, including biological, technical, managerial, environmental, and socio-political aspects.

Biological features recognised as critical to the high productivity of the crop are examined. These include its perennial and evergreen nature (giving a continuous year-round canopy cover intercepting a high proportion of incoming radiation), the year-round production of fruit bunches and the high partition of total assimilates into harvested product.

Scientific and managerial aspects contributing to the success of the crop include the significant genetic improvements and production of high quality planting materials, the development and application of finely-tuned agronomic practices, the appropriate scale and efficient organisation of oil palm plantations and the continuous R&D and good infra-structural support provided in the main producing countries.

The programmes of crop improvement through the utilisation of traditional breeding and selection methods, the development and benefits of vegetative propagation techniques using tissue culture and ongoing efforts to apply molecular and genetic engineering techniques to improve and modify oil composition, are reviewed.

Finally, the nutritional qualities of palm oil as a healthy component of diet are briefly described.

Media summary
Intensive R & D on crop physiology, productivity and improvement account for the sustainable production of palm oil and its associated products.

Key Words
Oil palm, oil yield, breeding and selection, cloning and genetic engineering, sustainable production.

Introduction
From its home in West Africa, the oil palm (*Elaeis guineensis* Jacq.) has spread throughout the tropics and is now grown in 16 or more countries. However, the major centre of production is in South East Asia (SEA) with Malaysia and Indonesia together accounting for around 83 % of world palm oil production in 2001. The recent changes in world mature areas are shown in Table 1. Malaysia is presently the world's leading exporter of palm oil having a 60 % market share and palm oil is second only to soybean as the major source of vegetable oil.

Oil palm production in Malaysia presently occupies around 3.7 million hectares of which over two million are in Peninsular Malaysia and the rest in the East Malaysian states of Sabah and Sarawak. Production is divided between large estates managed by publicly listed companies, smaller independent estates, independent smallholders and government smallholder settler schemes.

With good quality planting materials and agronomic practices, oil palm begins producing the oil-bearing fruit bunches as early as two and a half years after planting. While the lifespan of oil palm, as demonstrated by specimens planted in the Bogor Botanic Garden, Indonesia, is at least 120 years, the crop is generally grown for 25-30 years before being replanted. This is mainly because old palm becomes too tall to harvest economically.

Both the public and private sectors carry out oil palm research and development (R&D). In Malaysia, the Palm Oil Research Institute of Malaysia (PORIM) was set up in 1974 and was merged in 2000 with the Palm Oil Licensing Authority (PORLA) to form the Malaysian Palm Oil Board (MPOB). MPOB now deals with all aspects of oil palm and palm oil development and provides regulatory, training and technical advisory services to all sectors of the industry. Other research organizations that conduct research on oil palm and palm oil include the Indonesian Oil Palm Research Institute (IOPRI), Nigerian Oil Palm Research Institute (NIFOR), CENIPALMA in Columbia, CIRAD in France and Bah Lias Research Station in Indonesia. In Malaysia there are also many local plantation companies with R&D facilities such as FELDA, Golden Hope, United Plantations and Applied Agricultural Research.

The intensive research on oil palm and palm oil globally accounts for its significant contribution and status in the oils and fat market. In Malaysia, the success of the oil palm is attributed to many factors, which include favourable climatic conditions, well-established infrastructure, management skills and technology for oil palm cultivation and a land ownership structure which favours estate type of agriculture. Nevertheless, to stay competitive and to ensure agricultural sustainability (that is economic, social and environmental), appropriate R&D in various disciplines such as crop physiology, agronomy, genetics, tissue culture and biotechnology, must be strategically planned and implemented. The paper aims to provide a comprehensive overview on achievements in the areas mentioned and examine the potential of oil palm as a sustainable crop in the future.

Crop physiology

Understanding of basic physiological processes of the oil palm and how these relate to production and management of the crop continues to be a challenging and active area of investigation.

Early work in Malaysia laid many of the foundations needed for basic physiological, agronomic and breeeding studies by establishing non-destructive methods of assessing leaf area and dry matter production (DMP) (Hardon *et al*., 1969; Corley *et al*., 1971a). These have since greatly facilitated the estimation of productivity and its response to climatic and edaphic variables (Squire, 1985; Henson and Chang, 2000).

At this time also was first developed the idea that vegetative DMP takes prioity over bunch DMP when assimilates are limiting (Corley *et al*., 1971b). This has proved to be a very useful concept in explaining palm responses to planting density (Corley, 1973), edaphic factors (Squire, 1985) and in the modeling of productivity (van Kraalingen *et al*., 1989).

Crop growth analysis in terms of light interception, light-use efficiency and partitioning of assimilates was first applied to oil palm by Squire (1984). This has proved to be a useful approach, permitting the relative importance of these aspects to be identified during crop development. For young palms the early expansion of the oil palm canopy to facilitate radiation capture is of crucial importance for yield (Henson, 1991a), while the efficiency of radiation conversion to dry matter becomes more important later on once the canopy reaches full expansion (Henson and Chang, 2000). The exploitation of the rapid leaf expansion trait in breeding has been recommended by Breure (1985) while planters recognise the importance for yield of ensuring good establishment through optimising planting methods (Nazeeb, 1997).

It is now realised, that in addition to radiation and soil moisture, atmospheric humidity strongly influences photosynthetic capacity of oil palm and that both humidity and radiation need to be considered when evaluating climatic effects on yields. Low humidity restricts stomatal opening and hence CO_2 uptake (Smith 1989; Henson, 1991a). This finding may have implications for the location of new plantations and for predicting responses to climatic perturbations such as haze events (Henson, 2000).

Significant gaps in present knowledge remaining to be filled include the amount of assimilated carbon needed to maintain the root system and the minimum root system required to serve the needs of the palm for water and nutrient uptake. Minirhizotron tubes with a camera attachment are currently being used to monitor root turnover (Mohd. Haniff and Mohd. Roslan, 2003). Combined with destructive sampling this method should give a fuller picture of root activity and total assimilate requirements.

Crop productivity

The oil palm has the distinction of being the most productive of all oil crops with an average yield in major producing countries of about 3-4 tonnes of mesocarp (palm) oil/ha/year (Table 2). By contrast, the yields of most competing oil crops are typically less than one tonne/ha/year. This means that the productivity of oil palm is at least 3 - 8 times more than most oil seed crops. Thus, only 7 million hectares of oil palm are required to supply 20% of the world demand for oil and fats (1.09 billion tones), compared to the 80 million hectares of oilseeds needed to supply another 24% of this demand (Murphy, 2003).

In addition, oil palm also produces c. 0.5 tonne/ha/year of kernel containing c. 47% kernel oil. The kernel and mesocarp oils differ in fatty acid composition and hence have different uses, including both food and non-food. The kernel meal or cake is also of economic value as a source of animal feed protein.

Oil yields of the best plantings and in the peak years of production are much higher than the above figures. As an example, on a coastal soil with a high fertility status and constant water supply, palms at 9 years after planting had a standing dry biomass of 56 tonnes/ha and an annual total dry matter production (TDMP) of 36.7 tonnes/ha. The partitioning of TDM between fruit bunches (BDM) and vegetative dry matter (VDM) resulted in a bunch index (BDM/TDM) of 0.46 and a harvest index (palm oil/TDM) of 0.185, so the oil yield was 6.8 tonnes/ha. These figures neglect the kernel oil. Since the mesocarp oil contains over twice the energy of VDM the total 'non-oil equivalent' biomass production was over 44 tonnes/ha/year and the BI and HI in energy terms were 0.55 and 0.32 respectively.

How does the oil palm attain such yields despite being a C3 photosynthesis crop ? Firstly, its photosynthetic capacity is relatively high for an arborescent perennial, with the rate at light saturation approaching at least 25 $\mu mol/m^2/sec$ (Dufrene and Saugier, 1993). Secondly, at a commercial spacing of 130-150 palms/ha, under good conditions a full canopy cover is obtained by the 5-6th year after planting when the leaf area index (LAI) is around 6. By ten years 96 % of photosynthetically-active radiation (PAR) is intercepted while the mean interception value over the lifetime of a planting is about 88 % (Squire and Corley, 1987). Thirdly, being a tropical perennial crop with continuous year-round fruit production it is able to fully exploit resources provided limitations such as water deficits and pest and disease attacks are minimal.

Yield potential

There have been various attempts to estimate the theoretical maximum yield of the oil palm. By combining the maximum levels observed for individual yield components, Corley (1983) concluded that 17 tonnes mesocarp oil/ha/year should be possible. Subsequently, an even higher value of 18 tonnes/ha/year was postulated based on additional considerations of dry matter partitioning within the bunch (Corley, 1998). Breure (2003) in considering the matter further, concluded that a more realistic estimate, given the often mutually antagonistic relationships between yield components, would be from 10-11 tonnes/ha/year. This is similar to the maximum yields already achieved in several trials (breeder's materials 10 –12 tonnes/ha/year) (Rajanaidu and Jalani, 1990; Lee and Toh, 1991). In the commercial setting, a company officially reported the oil yield of its nine plantations to range from 6.51 to 7.45 tonnes/ha/year. In general, with good planting materials, soil condition and agricultural practice, the average yields of commercial plantations range from 5 to 7 tonnes/ha/year (Henson 1991b). The challenge is therefore to narrow the gap between the national average/commercial yield and the yield potential, both through crop improvement and management.

Crop improvement

Breeding and Genetics

The four African *Elaeis guineensis* palms brought over by the Dutch in 1848, and planted in Buitenzorg Botanical Garden (now Bogor) Indonesia laid the foundation for the oil palm industry in Malaysia and Indonesia. From these, the Deli *dura* palms with unique and favourable fruit qualities were developed. The Deli *dura* population is widely utilized for seed production and in genetic improvement programmes in Malaysia and Indonesia. The most cultivated high yielding oil palm variety, the thin shell *tenera* (oil:bunch (O/B) >20%) is produced when the thick shell *dura* (O/B ~ 17%) crosses with the shell-less *pisifera*. The *pisifera*, which is female sterile is used as the pollen source.

Apart from raising the total yield of fresh fruit bunches (FFB), breeding and selection also focus on achieving high FFB oil and kernel content. The quality of the oil in terms of a high level of unsaturation [high iodine value (I.V)] and minor but important constituents such as vitamin E and carotenoids, is also being selected for. Vegetative characters are also taken into account where reduced rates of trunk extension and long bunch stalks are desirable attributes to facilitate harvesting while compact palms may allow higher planting densities of up to 180 palms/hectare (Basri *et al*., 2003).

Elaeis oleifera, an oil palm species endemic to South and Central America readily hybridizes with *Elaeis guineensis*. This American species offers several desirable traits including slow height increment, high unsaturation and resistance to disease such as *Fusarium* wilt, which can be introgressed into the economically important *Elaeis guineensis*.

Previously, seed production solely relied on the Deli *dura* as the maternal parent with the exclusive use of the AVROS *pisifera* as the pollen source. Systematic prospections to collect oil palm genetic materials were carried out by Malaysian researchers to widen the genetic base for breeding and to ensure conservation of palm genetic resources. The collection for *Elaeis guineensis* started in Nigeria in the early 1970's followed by other countries in Western and Central Africa and the Island of Madagacar (Rajanaidu and Jalani, 1994a, b, c). *Elaeis oleifera* genetic materials from six Central and South American countries were also collected (Rajanaidu and Jalani 1994c). MPOB now has the largest oil palm germplasm collection in the world. There is indication based on restriction fragment length polymorphism (RFLP) analysis that a high level of genetic variability exists in the natural population from Africa, which can be exploited for genetic improvement through breeding and selection (Maizura, 1999).

These germplasm materials together with elite *dura* and *pisifera* have been used in the development of the PORIM Series (PS) of planting materials (now MPOB). High yielding and dwarf palms (PS1) with potential oil yield of 7.7 tonnes/ha/year and height increment of only 40cm/yr (PS1) compared to the normal 5-6 tonnes/ha/year and 45-75cm/year and high I.V (iodine value) palms (PS2) with I.V. in excess of 60 compared to 53 of current planting materials, were developed after intense selection of the Nigerian germplasm collection. These materials have been distributed to the oil palm industry for parallel development by crossing with industry breeding materials and subsequent large-scale field evaluation (Kushairi *et al.*, 2000). Another planting material developed using the Nigerian germplasm is PS3 (high kernel/bunch of 10 -15 % compared to the normal 5-7 %). More recent selections include PS4 (*Elaeis oleifera* with high carotene up to 2,220 ppm compared to 500-700 ppm in *E. guineensis*), PS5 (high vitamin E, of up to 1247 ppm compared to the normal 500ppm) and PS6 (high bunch index of 0.68 compared to 0.3 in current DXP).

Breeding programmes involving *E. oleifera* are not being given as much emphasis as those with *E. guineensis.* Nevertheless, there are efforts in producing interspecific *E. oleifera* and *E. guineensis* hybrids for improving I.V. and developing short and compact palms (Escobar and Alvarado, 2003; Chin *et al*., 2003). Due to inferior fruit set and problems associated with excessive vegetative vigour of the F1 hybrids, a series of backcrosses to *E. guineensis* are essential to improve the yield and vegetative characters. Programmes to map the oil palm genome by MPOB and CIRAD using RFLP, AFLP and macrosatellite probes will enable marker-assisted selection to be carried out eventually (Rajinder *et al*., 2001). In addition, the genomic *in situ* hybridization technique (Madon *et al*., 1999), which can differentiate the genome of the two species, proved a valuable aid to breeders in monitoring the inheritance of *E. guineensis* in the backcross progenies.

Tissue culture

The earliest reports of successful vegetative propagation of oil palm by tissue culture were in the mid 1970s (Jones, 1974; Rabechault and Martin, 1976). Now, about 20 oil palm laboratories are in operation throughout the world with capacity ranging from 10,000 – 200,000 plantlets per year (Zamzuri *et al*., 1999). As compared to seed production, tissue culture of oil palm offers several advantages (Sogeke, 1998). It allows rapid multiplication of uniform planting materials with desired characteristics. This enables improvement of planting materials using existing individuals which have all or most of the desired qualities such as good oil yield and composition, slow vertical growth and disease resistance. Additionally, it also opens new avenues for producing novel planting materials via genetic engineering, because tissue culture is the means for regeneration of tissues transformed with genes for traits of interest.

Oil palm tissue culture is employed both as a means for producing good *tenera* palms for commercial planting and to multiply good parents (both *dura* and *pisifera*) for seed production. It is also practised to expedite the exploitation of progenies from interspecific *E. oleifera* X *E. guineensis* crosses. Based on current demand for oil palm seeds in Malaysia and other countries, Zamzuri *et al*., (1999) estimated that there is a ready market for more than 100 million tissue culture plantlets annually.

Tissue culture laboratories are linked to an effective oil palm breeding and improvement programme to ensure supply of desired explants. Ortets selected are supported by at least four years of field data showing good performance on oil yield, vegetative characteristics such as low height increment and physiological traits such as bunch index and oil characteristics (Rohani *et al*., 2000). Oil yield is determined by the oil extraction rate (OER) or O/B and weight of FFB. Since O/B has been demonstrated to be highly heritable and transmitted from ortets to ramets, it is given emphasis in ortet selection. Leaves, inflorescences and roots can be used as explants but young leaf spears are often preferred. Leaf explants can be easily surface sterilized and give higher clonability rates (Rajanaidu *et al*., 1997). From the explants, callus is initiated, followed by embryogenesis, shoot and root regeneration, hardening of ramets for the nursery and finally field evaluation. The regeneration process through oil palm tissue culture takes 2-4 years depending on genotype. Zamzuri (1998) introduced the double-layer rooting technique for oil palm. In this technique the solid shoot development medium is overlayed with liquid root initiation media. This improves the productivity of the worker 18-fold and reduces the cost of rooting by about 94%.

Based on field performance data from various sources an improvement of oil yield between 20% to 30% over seedling planting materials is achievable by clonal materials (Soh *et al*.,2001). There are indications that selection for resistance to major oil palm diseases will be easier based on differences in susceptibility shown by clones to *Ganoderma*, *Fusarium* and blast (Purand-Gasselin *et al*., 1999). The difficulty lies in achieving true-to –type reproduction of plants selected as ortets, especially with the incidence of mantled abnormality. The percentage of abnormality in the field has generally been maintained at a tolerable level of less than 5% (Maheran *et al*., 1995). Prudent selection of good ramets at both *in vitro* and nursery stage is practised to reduce abnormality level. Maheran *et al*. (1995) reported that clones appearing normal at both stages gave a low level of abnormality in the field (about 2.2%). It was estimated that the initial investment on clonal materials will be covered in the sixth year (Zamzuri *et al*., 1999), after which the returns from clonal materials will be much higher than conventional *dura* X *pisifera* planting materials due to their higher productivity.

Favourable reports of plantings of liquid culture ramets suggested that the technology can be exploited for oil palm clone production (Soh *et al*., 2001). The liquid culture system offers advantages in reproducibility, versatility and efficiency with high potential for scaling up propagule production. In parallel with developing a liquid culture system, MPOB is employing bioreactor technology which will lead towards a semi or full automation of the process of oil palm clonal production (Tarmizi *et al*., 2003).

Recent results from genetic marker and genome wide methylation studies indicated that the tissue culture abnormalities in oil palm arise from an interplay of genetic and epigenetic mechanisms. Various efforts are geared towards developing diagnostic tools for predicting genetic predisposition to abnormality. These include global gene expression analysis via DNA microarray, genetic mapping and the candidate gene approach. It is anticipated that an effective screening process, preferably at the ortet stage, will provide greater confidence to the industry in producing and utilising clones (Cheah, 2003).

Genetic engineering

Production of novel high-value products by genetic engineering provides avenues for diversification to increase the economic value of oil palm. The oil palm being highly productive and perennial in nature has significant advantages over other crop species for such endeavours. MPOB’s first initiative in genetic engineering is to produce high oleate palms for the industrial feedstock and liquid oil market. The estimated value for high oleate palms is USD 1,500/ha/year if the oleic acid content is > 65%. More recent targets in genetic manipulation include high stearate palms as cocoa butter substitute, nutraceutical oils enriched in palmitoleic acid and lycopene and biopolymers for industrial applications (Sambanthamurthi *et al*., 2002)

Palm fruits have two storage tissues; mesocarp and kernel, that can be the target for accumulating genetically manipulated products. The substrates and intermediates for the production of storage oil or protein in these tissues may be channelled to alter the levels of existing products or to produce novel value-added products without deleterious effects on the plants. The mesocarp and kernel oil differ in fatty acid composition as well as the period at which the oil accumulates during oil palm fruit development. The promoter sequences corresponding to a mesocarp and a kernel-specific gene of the oil palm have been isolated. The expression profile of the mesocarp-specific gene in different oil palm tissues, as well as at different developmental stages of the mesocarp and at the cellular level (as shown by Northern blot analysis and RNA *in situ* hybridization, respectively) indicated a strong correlation with that of a fatty acid biosynthetic gene, stearoyl-ACP desaturase. Transient expression analysis of oil palm tissues bombarded with promoter:reporter construct further confirmed that the promoter corresponding to the mesocarp specific gene is functional with a mesocarp-specific promoter activity (Siti Nor Akmar and Zubaidah, 2002). Backbone transformation vectors containing the mesocarp-specific promoter, nopaline synthase (NOS) terminator, with and without plastid targeting sequence from oil palm stearoyl-ACP desaturase gene were produced. In these constructs, a rare cutter site was introduced (*Asc* I) to serve as the site for insertion of target genes (Siti Nor Akmar *et al*., 2003).

The production of high oleate and high stearate palms involves genetic manipulation of the fatty acid biosynthetic pathways in the mesocarp (Figure. 1). Biochemical studies and gene isolation were carried out for important enzymes required for the production of these fatty acids (Siti Nor Akmar *et al*., 2001). A partial cDNA clone encoding acetyl-CoA carboxylase (ACCase), an enzyme catalyzing the first committed step in lipid biosynthesis and expected to be an important flux-controlling enzyme has been isolated. β-ketoacyl ACP synthase II (KAS II) and acyl-ACP thioesterase are the key enzymes for genetic manipulation for the production of high oleate and stearate palms. The strategy is to overexpress KAS II which catalyses the elongation from C16:0 to C18:0 and to antisense palmitoyl-ACP thioesterase in order to reduce the production of palmitate for channeling towards increasing oleate. Biochemical studies have been performed on both enzymes and the full-length cDNA clones have been obtained and used in producing gene constructs containing mesocarp-specific promoter for transforming oil palm. To avoid spill over from C18:1 to C18:2, down regulation of the oleoyl-CoA desaturase is essential. Thus far the partial cDNA clone encoding this gene has been isolated. The full-length cDNA clone for stearoyl-ACP desaturase has been isolated and the antisense form introduced into palms for increasing stearic acid.

The genetic engineering programme involves collaboration and co-ordination between various research disciplines namely the molecular biologists to provide the genes and promoters and to carry out oil palm transformation, tissue culturists for regenerating the transformed tissues and breeders to assist with field evaluation. The particle bombardment method has been developed and is now being used routinely for transforming oil palm (Parveez , 2000). Research to establish the *Agrobacterium* mediated transformation technique is also being intensified. MPOB has also set up an Institutional Biosafety Committee to address the various issues related to GM palms and field release of transgenic palms for evaluation. To date, there is no genetically modified palm oil though active R&D is in progress.

Crop management

Agronomy and nutrition

The oil palm is recognized as having a high demand for nutrients; not surprising in view of its high dry matter production. Nutrients that are removed continuously through the harvested FFB or sequestered in the standing biomass need replacing if soil nutrient reserves are not to become depleted. From previous studies, it has been estimated that for Malaysian soils between 0.5 and 1.1 kg/palm /year of N, 0.7 and 1.1 kg/palm/year of P_2O_5, and 0.5 to 2.0 kg/palm/year of K_2O are needed to make good the shortfall in soil nutrient supply after taking into account expected losses of the applied nutrients (Tarmizi, 2000). In addition, it is important that for yields to be maximized, the nutrients applied are balanced.

Past studies have shown that empty fruits bunch (EFB) mulching significantly improved oil palm yield (Hamdan *et al.*1998). EFB generally contains 0.80 % N, 0.22 % P_2O_5, 2.90 % K_2O, and 0.30 % MgO on a dry weight basis. Yield improvement ranging from 5 % to 23 % has been achieved depending on soil type. Hamdan *et al*. (1998) showed that nutrients from 60 tonnes/hectare/year of EFB, without any inorganic fertilizer, were sufficient to support palm growth. Nevertheless, because of the high C/N ratio, a lower rate of EFB application is made with supplements of inorganic fertilizer. This approach maintains soil productivity through better soil structure and reduces fertilizer cost for immature palms by as much as 58 %, and by 5 % for mature palms.

The high cost of inorganic fertiliser encourages best-developed practices designed to optimise fertiliser use and minimise nutrient losses. For example, it is routine to base fertiliser recommendation on foliar analysis so that observed deficiencies can be corrected and an appropriate balance maintained between different elements. Foliar analysis may be supplemented by analysis of rachis tissue (which acts as a nutrient store) and soil. Using such information, application rates and fertiliser sources are objectively determined, often with the aid of customised computer programmes such as the MPOB Oil Palm Nutrient System (OPENS). The technology for producing a fertilizer management map has been developed for oil palm and current investigation is on variable rate technology (VRT) required for the implementation of precision agriculture.

An innovative replanting technique has been developed where young palms are planted directly amongst old crop residue piles to improve accessibility and efficiency of nutrient utilization (Khalid *et. al*. 2000). This technique offers greater synchrony between nutrient release and plant uptake in terms of space and time compared to the standard practice. The residues contain 642 kg N, 58 kg P, 1384 kg K and 156 kg Mg per ha. In terms of inorganic fertilizers, this is equivalent to 3.06 tonnes of sulphate of ammonia, 0.37 tonnes of Christmas Island rock phosphate, 2.77 tonnes of muriate of potash and 1.0 tonne of kieserite.

Environment

Increasingly, there is recognition worldwide of the necessity to reconcile agriculture practices with the need for environmental conservation. Ensuring that agricultural operations do not damage the environment also, in the long-term, contributes to the sustainability of cropping systems.

In several areas, environmental considerations are already well catered for. These include the minimum use of chemicals, the adoption of integrated pest management, judicious use of inorganic fertiliser, recycling of palm biomass within the plantation and between mill and plantation, zero-burning practice on clearance, and soil conservation measures. Examples of the latter including terracing of hilly areas, construction of drains and preservation of natural watercourses, use of silt pits and of cut fronds across slopes to minimise erosion and runoff.

The use of beneficial plants, such as *Cassia cobanensis* and *Euphorbia heterophylla*, as sources of nectar for parasitoids, is being widely adopted by plantations to keep populations of oil palm insect pests in balance with nature (Basri and Norman, 2000). This has led to a reduction in the use of insecticides for bagworm and nettle caterpillar control.

Several features of an oil palm plantation resemble those of the natural forest cover that it often replaces. As a perennial tree crop oil palm, at least from the seventh or eighth year onward, provides a continuous and dense canopy cover and also recycles nutrients and organic matter within the ecosystem. Unlike most other oil crops, little or no tillage is involved in its cultivation which minimises the oxidation and loss of organic matter which may otherwise occur. The canopy not only provides protection to the soil from the worst impacts of heavy rainfall, it also increases humidity while reducing air and soil surface temperatures, all factors which go towards providing a favourable microclimate for many co-existing species.

Environmental considerations are equally important in the processing sector of the industry. Legislation imposes limits to the nature and amounts of discharges to the atmosphere and waterways by mills and refineries. However, mill ‘waste’ products, which were once viewed as embarrassing liabilities are now viewed as co-products of increasing potential value. In addition to EFB and palm oil mill effluent (POME) as nutrient sources in the plantation, the use of excess fibres in manufacturing, the recovery of

POME solid for animal protein, the generation of biogas from the effluent ponds and use of surplus boiler energy to generate electricity, are further examples, all of which serve to promote a 'zero-waste' concept. Current effort on R&D at MPOB is to minimize the production of greenhouse gasses (GHG) and all existing practices in the field, mill and refinery are being examined. Reduction of GHG will assist in slowing down of climate change.

Crop oil quality and nutritional value
While palm oil has a wide range of uses, both food and non-food, some 80% of the oil produced serves as an important source of vegetable fat for an increasing number of people. The crude oil comprises of approximately half saturated (mainly palmitic) and half unsaturated (mainly oleic) fatty acids. Saturated fats have in the past been widely regarded as being undesirable dietary components due to their association with high cholesterol levels and heart disease. However, there are various forms of cholesterol, not all bad, and recent studies have shown that intake of palm oil raises levels of the high-density lipoprotein (HDL, 'good' cholesterol) at the expense of the low-density lipoprotein (LDL, 'bad' cholesterol.).

Unsaturated oils such as soybean are usually hydrogenated to render them less liquid and more suitable for the manufacturing of margarines and other products. This essentially converts them into saturated fats while at the same time generating *trans*-fatty acids that do not occur naturally. As such *trans* isomers have been found to impose a risk of heart disease there is now a preference for *trans*-free oils such as palm oil. Palm oil is therefore promoted both as a 'balanced' oil (having equal saturated and non-saturated content) and one that is *trans*-free (Wahle and James 1993; Ascherio 2002).

Other plus points, already referred to above, concern the vitamin and carotenoid contents of the oil. Vitamin E is a free radical scavenger, with anti-cancer properties, as are the carotenes. Red palm oil, which is the product of a new technology that aims to preserve these minor components, has a further role to play in a healthy diet. More recently, it has been shown that the oil palm is a rich source of phenolic antioxidants, a minor fraction of which enters the oil phase and confers further health benefits.

Thus, from the many studies now undertaken, the image of palm oil as an undesirable 'tropical oil' has changed and it is now accepted worldwide as a healthy dietary ingredient.

Oil palm potential – some conclusions
Palm oil is an important food and a major source of lipids. World population continues to increase, thus creating increasing demand. As such, oil palm will continue to be cultivated worldwide. The growing of oil palm needs to be economically viable and environmentally sustainable. This is aided by intensive R &D on the crop, aspects of which have been discussed in the paper.

The effort to narrow the gap between commercial yield and potential yield will continue to be given priority. Materials, which produce 7 tonnes oil/ha/year in commercial plantations, have been produced. The low overall national yield averages suggest that besides good planting materials, good crop management and environment are critical for the realization of yield potential. In addition it is important that the plantations quickly adopt new technologies, particularly in fertilizer management. The possible adoption of precision agriculture in the future will further optimize fertilizer application so that achieving site yield potential can be a reality. This will be a challenge for researchers, extension agents and plantation managers.

An understanding of the basic physiology of the palm can enhance its management as a decision can be based on scientific rationale. There is a need, however, to develop an oil palm model that examines all physiological factors associated with productivity in relation to different environmental conditions. From this model, an ideal type palm can be generated for various soils and environments.

Current breeding and genetics efforts worldwide are focused on high oil yield per unit area of land with a view to maximizing returns. This will continue to be the challenge in the future until the yield potential of each site is fully achieved. Besides oil yield, breeding populations with many desired traits such as high carotene and high vitamin E have been identified as mentioned above. The close collaboration between MPOB and the private sector will ensure that these traits will eventually be commercially exploited. This should be possible after 10 years of progeny evaluation resulting in products whose values are much higher than current palm oil. This will add more strength to the economics of oil palm cultivation.

Concurrently, within MPOB, a multi-disciplinary team has been formed to work on the development of high carotene from *E. oleifera* as a neutraceutical product. The aim is to produce high carotene containing capsules.

Other areas where intensive R&D have been undertaken to create value addition include biomass and oleochemicals. Many technologies to convert oil palm biomass into valuable products such as pulp and paper, medium density fibre board (MDF), moulded particle board, plywood and lumber have been developed. One remarkable success is the utilization of oil palm fibres as fillers for the production of thermoplastic composite used in the Malaysian national car. Unending efforts are being made together with the industry to commercialize the other products

Oleochemicals are essentially chemicals derived from natural plant oils and fats. They are important because they can be further processed into high value added products. To expedite research in this area, the Advanced Oleochemical Technology Center was established at PORIM in 1994 to spearhead the development of downstream activities related to oleochemicals. The center focuses on polyurethanes, polyols, inks, surface coatings, palm-based herbicides, surfactants and cosmetics. Pilot plants such as those for polyol and the methyl ester sulphonates are built as a step towards commercial production.

In the past the production of clones through tissue culture has been plagued with high occurrences of abnormality. To date there is a much better understanding of the factors associated with abnormality and on how to reduce its incidence though the problem has not been fully resolved. However, the level of abnormality in the field is now less than 5 % and several major plantation agencies are beginning their replanting programmes with clones. Such a move will result in yield increasing by as much as 30 %. The development of suspension culture and bioreactor technology will further allow clones to be produced over a shorter period compared to the use of traditional solid culture.

Significant advances have been made in oil palm genetic engineering over the last 10 years. Virtually all the genes and promoters required to modify the fatty acid biosynthetic pathway have been obtained. Technology is currently available to produce three novel products, namely high oleate, high strearate and high palmitoleic. Nevertheless, several pressing issues need to be addressed in the immediate future such as developing a better transformation method with low copies of trans-genes, and ensuring bio-safety, and public acceptance.

This paper demonstrates that the R&D on oil palm has also aimed to fulfill environmental needs. Any good agricultural practice needs to be backed by supporting evidence. The industry as a whole is serious in promoting environmental sound practices and these are increasingly being adopted.

Thus, for the future, the oil palm is geared to undergo a more efficient production system that will produce more yields, thus translating into lower production costs. The potential of oil palm is enormous and many opportunities exist for the creation of new industries. The sustainability of oil palm will gain more ground as results of future R &D unfold for adoption by the industry.

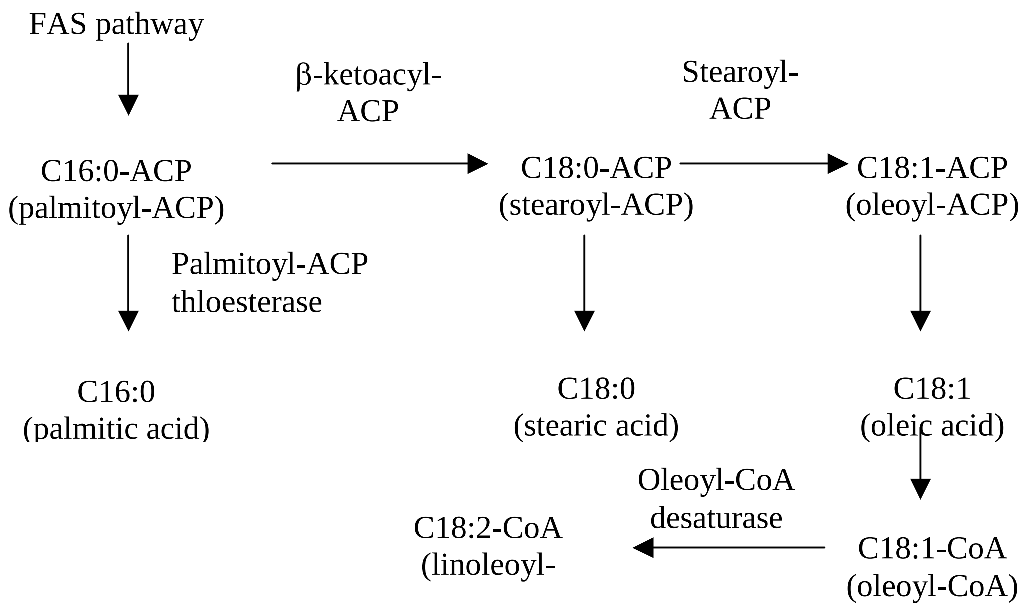

Figure 1: Fatty acid biosysnthesis in plants (FAS = fatty acid synthase)

Table 1. World mature areas of oil palm ('000 ha)

Countries	1980	1990	2000	Annual growth rate (%) 1990-2000*
Indonesia	230	617	2014	12.6
Thailand	15	94	199	7.8
Malaysia	805	1746	2941	5.5
Colombia	27	81	134	5.2
Others	151	527	731	3.3
Nigeria	220	270	360	2.9
Ivory Coast	100	128	139	0.8
Total	1756	3463	6563	6.6

(After Yusof and Chan, 2003)

Table 2. World production, yields and areas of oil crops

Crop	Production ('000 t)	Oil/ha/year (t)	Area (million ha)	(%) of total area
Soyabean	25 483	0.46	55.398	63.48
Sunflower	9 630	0.66	14.591	16.72
Rapeseed	14 237	1.33	10.704	12.26
Palm Oil	21 730	3.30	6.563	7.52

(After Yusof and Chan, 2003)

Acknowledgements
The authors would like to thank Datuk Dr. Yusof Basiron, the Director General of Malaysian Palm Oil Board for permission to present this paper. Comments made by Dr. Chan KC, on the manuscript and Dr. Ravigadevi S on nutritional issues are appreciated.

References

Ascherio A (2002). Diet fat and risk of CHD: New developments. In "Enhancing Oil Palm Industry Development through environmentally technology" (Eds. Z. Poeloengan *et al*.) Indonesian Oil Palm Research Institute. pp. 60-65.

Basri MW, Maizura I, Siti Nor Akmar A and Norman K (2003). Oil palm. 'In Handbook of Industrial Crops'. (Eds. V L Chopra and K V Peter) The Haworth Press, New York. (In press)

Basri MW and Norman K (2000). In 'Advances in Oil Palm Research' (Eds. B. Yusof, B S Jalani and KW Chan) Vol. 1, pp. 466-541.

Breure CJ (1985). Relevant factors associated with crown expansion in oil palm (*Elaeis guineensis* Jacq.*). Euphytica*, 34, 161-175.

Breure K (2003). The search for yield in oil palm: basic principles. In 'The oil palm. Management for large and sustainable yields' (Eds. T. Fairhurst and R. Hardter). Potash & Phosphate Institute/Potash Institute of Canada and International Potash Institute. pp. 59-98.

Cheah SC (2003). Understanding the causes of oil palm tissue culture abnormalities on the road

to commercialization. Proceedings of the PIPOC 2003 International Palm Oil Congress. Agriculture Conference, pp. 121 – 128. MPOB.

Chin CW, Shuhaimi S, Mohd Nasaruddin M and Ng WJ (2003). Selection of elite ortets

from interspecific hybrids and backcrosses. Proceedings of the 2003 International Palm Oil Congress. Agriculture Conference, pp. 36 – 50. MPOB.

Corley RHV, Hardon JJ and Tan GY (1971a). Analysis of growth of the oil palm (*Eleais guineensis* Jacq.). I. Estimation of growth parameters and application in breeding. *Euphytica*, 20, 307-315.

Corley RHV, Gray BS and Ng SK (1971b). Productivity of the oil palm (*Eleais guineensis* Jacq.) in Malaysia. Experimental Agriculture, 7, 129-136.

Corley R H V (1973). Effects of plant density on growth and yield of oil palm. Experimental Agriculture, 9, 169-180.

Corley RHV (1983). Potential productivity of tropical perennial crops. Experimental Agriculture, 19, 217-237.

Corley RHV (1998). What is the upper limit to oil extraction ratio? Proceedings of International Conference on Oil and Kernel Production in Oil Palm - A Global Perspective. (Eds. N Rajanaidu, I E Henson and B S Jalani). pp. 256-269. Palm Oil Research Institute of Malaysia, Kuala Lumpur.

Dufrene E and Saugier B (1993). Gas exchange of oil palm in relation to light, vapour pressure deficit, temperature and leaf age. Functional Ecology, 7, 97-104.

Escobar R and Alvarado A (2003). Strategies in production of oil palm compact clones and seeds. Proceedings of the 2003 International Palm Oil Congress. Agriculture Conference, pp. 75 – 90. MPOB.

Hamdan AB, Ahmad Tarmizi M and Mohd Tayeb D (1998). Empty fruit bunch mulching and nitrogen fertilizer amendment: The resultant effect on oil palm performance and soil properties. PORIM Bulletin No. 37, 1-14.

Hardon JJ, Williams CN and Watson I (1969). Leaf area and yield in the oil palm in Malaya. Experimental Agriculture, 5, 25-32.

Henson IE (1991a) Limitations to gas exchange, growth and yield of young oil palm by soil water supply and atmospheric humidity. Transactions of Malaysian Society of Plant Physiology, 2, 39-45.

Henson, IE (1991b). Estimating potential productivity of oil palm. Proceedings of the 1990 ISOPB International Workshop on Yield Potential in the Oil Palm. (Eds. V Rao, I E Henson, and N Rajanaidu). Pp. 98-108. Palm Oil Research Institute of Malaysia.

Henson IE (2000). Modelling the effects of 'haze' on oil palm productivity and yields. Journal of Oil Palm Research 12, 123-134.

Henson IE and Chang KC (2000). In 'Advances in Oil Palm Research' (Eds. B. Yusof, B S Jalani and KW Chan) Vol. 1, pp. 97-145.Jones, LH (1974). Propagation of clonal oil palm by tissue culture. Oil Palm News 17, 1-8

Khalid H, Zin ZZ and Anderson, JM (2000). Soil nutrients dynamics and palm growth performance in relation to residue management practices following replanting of oil palm plantations. Journal of Oil Palm Research 12 (1), 25-45.

Kushairi A and Rajanaidu N (2000).). In 'Advances in Oil Palm Research' (Eds. B.

Yusof, B S Jalani and KW Chan) Vol. 1, pp. 39-96. Malaysian Palm Oil Board.

Lee CH and Toh PY (1991). Yield performance of Golden Hope OPRS D x P planting materials. The Planter 67, 317-324.

Madon M, Clyde MM and Cheah SC (1999). Application of genomic *in situ* hybridization (GISH) on *Elaeis* hybrids. Journal of Oil Palm Research, Special Issue (October 1999), 74 – 80.

Maheran A, Aw KT, Abu Zarin O and Chin CW (1995). Vegetative propagation of oil palm (*Elaeis guineensis*) from laboratory to field- FELDA experience. Proceedings of the 1993 International Palm Oil Congress. Agriculture Conference pp. 99-113. MOB.

Maizura, I. 1999. Genetic variability of oil palm (*Elaeis guineensis* Jacq.) germplasm collections using RFLP markers. PhD. Thesis. Universiti Kebangsaan Malaysia.

Mohd. Haniff H and Mohd. Roslan M N (2003). An improved minirhizotron for observing oil palm root development and turnover. MPOB Information Series MPOB TT No 179 Malaysian Palm Oil Board, Kuala Lumpur. 2 pp.

Murphy DJ (2003). Working to improve the oil palm crop. Inform 14 (11), 670-671.

Nazeeb M (1997). Agronomic practices to remain competitive in the oil palm industry. The Planter, Kuala Lumpur 73, 533-553.

Parveez GKA (2000). In 'Molecular Biology of Woody Plants'. (Eds. S.M. Jain and S.C. Minocha). Vol. 2, pp. 27-350. (Kluwer Academic Publishers)

Purand-Gasselin T, Konan KE, Bondonin L and Noiret JM (1999). In 'Performance of

DXP, Interspecific Hybrids and Clones', pp. 151-170.

Rabechault, H and Martin Jeane-Pierre (1976). Multiplication vegetative dupalmier a huile(*Elaeis guineensis* Jacq) a l'aidede cultures de tissue foliares. Compte Rendu Acad. Sci. Ser. D 283: 1735-1737.

Rajanaidu N and Jalani S (1990). Performance of D X P planting material in various parts of the world. Proceedings on Worldwide performance of D x P oil palm planting materials, clones and interspecific hybrids. (Eds. N Rajanaidu and B S Jalani)pp. 1-34. Palm Oil Research Institute of Malaysia.

Rajanaidu N and Jalani BS (1994a). Oil palm germplasm collection in Senegal. ISOPB Newsletter 10(1), 1-18

Rajanaidu N and Jalani BS (1994b). Germplasm collection in Gambia. ISOPB Newsletter 10(2), 1-16

Rajanaidu N and Jalani BS (1994c). Oil palm genetic resources – collection, evaluation, utilization and conservation. A paper presented at PORIM Colloquium on Oil Palm Genetic Resources. PORIM, Malaysia 13 September 1994

Rajanaidu N, Rohani O and Jalani BS (1997). Oil Palm clones: current status and prospects for commercial production. The Planter 73(853), 163-184.

Rajinder S, Cheah SC, Madon M, Ooi L C L and Rahimah AR (2001). Genomic

strategies for enhancing the value of the oil palm. Proceedings of the PIPOC 2001 International Palm Oil Congress. Agriculture Conference. pp. 3 – 17. MPOB.

Rohani O, Sharifah SA, Mohd Rafii Y, Ong M, Tarmizi AH and Zamzuri I (2000). In 'Advances in Oil Palm Research' (Eds. B Yusof, B S Jalani and KW Chan) Vol. 1, pp 238-331.

Sambanthamurthi R, Siti Nor Akmar A and Ahmad Parveez GK (2002). Genetic manipulation of the oil palm – challenges and prospects. The Planter, Kuala Lumpur, 78 (919), 547-562.

Siti Nor Akmar A, Sambanthamurthi R and Ahmad Parveez GK (2001). Genetic modification of

oil palm for producing novel oils. Proceedings of the PIPOC 2001 International Palm Oil Congress. Agriculture Conference. pp. 18-30. MPOB.

Siti Nor Akmar A and Zubaidah R (2002). Regulatory sequences for regulation of gene expression in plants and other organisms, and compositions, products and methods related thereto. Malaysian Patent Application No. PI 20021165.

Siti Nor Akmar A**,** Zubaidah R, Manaf MA and Nurniwalis W(2003). In 'Advanced Researches of Plant Lipid'. (Ed N. Murata, M. Yamada and I. Nishida). pp. 411 – 414 (Kluwer Academic Publishers)

Smith BG (1989). The effects of soil and atmospheric vapour pressure deficit on stomatal behaviour and photosynthesis in the oil palm. Journal of Experimental Botany, 40, 647-651.

Soh AC, Wong G, Tan CC, Chew PS, Hor TY, Chong SP and Gopal K (2001). Recent advances towards commercial production of elite oil palm clones. Proceedings of the PIPOC 2001 International Palm Oil Congress. Agriculture Conference. pp. 33-44. MPOB.

Squire G and Corley R H V (1987). Oil Palm. In 'Tree Crop Physiology'. (Eds. M R Sethuraj and A S Raghavendra). Pp. 141-167. Elsevier Science, Amsterdam.

Squire G R (1984). Light interception, productivity and yield of oil palm. Occasional report. Palm Oil Research Institute of Malaysia, Kuala Lumpur. 45 pp.

Squire G R (1985). A physiological analysis of oil palm trials. PORIM Bulletin, 12, 12-31.

Sogeke,A K (1998). Stages in the vegetative propagation of oil palm, (*Elaeis guineensis*) Jacq. through tissue culture. Journal of Oil Palm Research l0 (2), 1-9.

Tarmizi AM (2000). In 'Advances in Oil Palm Research' (Eds. B. Yusof, B S Jalani and KW Chan) Vol. 1, pp. 411-440.

Tarmizi AH, Norjihan M A, Samsul Kamal R, Zaitun R and Cheah SC (2003). Proceedings of the PIPOC 2003 International Palm Oil Congress. Agriculture Conference. pp.130 – 144. MPOB.

Van Kraalingen D W G, Breure C J and Spitters C J T (1989) Simulation of oil palm growth and yield. Agricultural and Forest Meteorology. 46, 227-244.

Wahle KWJ and James WPT (1993). Isomeric fatty acids and human health. European Journal of Clinical Nutrition 47, 828-839.

Yusof B and Chan KW (2003). Going back to basics: Producing high oil palm yields sustainably. Oil Palm Bulletin 46(2), 1-14.

Zamzuri 1, Mohd Arif S, Rajanaidu N and Rohani O (1999). Commercial feasibility of clonal oil palm planting material production. PORIM Occasional paper No. 40, 52 pp.

Zamzuri 1 (1998). Efficient rooting of oil palm in vitro plantlets using double- layer technique. PORIM Bulletin No. 36, 23-36.