Towards Higher Yield Potential, Production and its Prediction in Oil Palm

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ABSTRAK

Pada ketika industri sawit sedang bersiap sedia untuk melangkah ke abad 21, kini adalah masa yang sesuai untuk memeriksa dan mengambil pelajaran daripada 100 tahun pertama sawit berada di Malaysia. Hujung abad ini bukan sekadar masa untuk melihat pematuhan kepada Y2K, tetapi apa yang lebih penting ialah untuk menilai tiga P - potensi, pengeluaran dan peramalan hasil - bagi menentukan industri sawit terus bertambah maju. Walau bagaimanapun, di dalam penilaian ini perlu diingat bahawa apa yang baik pada masa yang lepas tidak semestinya baik pada masa akan datang.

Semasa abad yang lepas, pembaikan yang signifikan dari segi hasil sebenar dan potensi sawit telah dilakukan melalui proses biakbaka dengan mengacukkan individu yang terbaik. Akhir ini pula proses bioteknologi telah digunakan. Sedang biakbaka memberi tumpuan kepada pengeluaran baka yang rintang kepada penyakit dan perosak, bioteknologi pula mempunyai skop bukan sekadar untuk meningkatkan hasil malah boleh mengubah kualiti produk (minyak).

Peningkatan potensi hasil mesti disertai juga dengan usaha untuk mencapai dan meningkatkan kualiti minyak yang baik melalui penggunaan pelan pengurusan yang telah terbukti seperti systems approach. *Banyak faktor pengurusan seperti baka, kepadatan tanaman, kematangan, kesuburan tanah, kawasan, corak penghasilan, kawalan perosak dan penyakit, penjagaan dan penuaian, pemprosesan dan penyimpanan memberi kesan terhadap hasil dan kualiti minyak. Malah yang paling penting sekali ialah baka sawit. Setiap faktor mesti dikaji secara holistik supaya ia boleh diatasi secara berasingan. Adalah penting untuk diingat bahawa setiap satu faktor atau gabungan beberapa faktor boleh memberi kesan kepada hasil dan kualiti minyak dan seterusnya nilai dan keberuntungan tanaman.*

Dalam alaf baru, penanaman sawit bertujuan semata-mata untuk minyaknya mungkin tidak tepat lagi kerana serat daripada biojisim sawit menjadi penting untuk dijadikan komposit. Oleh itu, penyelidikan sawit perlu menumpukan kepada produktiviti keseluruhan kerana minyak dan biojisim adalah produk ekonomi. ' Produktiviti ' sawit adalah jumlah bahan kering yang dihasilkan dan apa yang menjadi penting ialah tenaga yang digembeling untuk menghasilkannya. Produktiviti sawit bergantung pada tiga faktor- biasan tenaga suria, bahagian tenaga suria yang dipintas oleh kanopi pokok dan kecekapan penukaran cahaya suria yang dipintas kepada bahan kering. Jika kedua produk ekonomi tersebut mempunyai nilai yang berbeza, maka pembahagian bahan kering kepada produk-produk tersebut akan juga menjadi penting. Setiap satu daripada empat faktor (tiga + pembahagian) dikaji untuk mendapat kefahaman yang lebih berkaitan dengan peranan faktor tersebut terhadap hasil.

Pada masa kini, minyak sawit dan minyak isirong sawit adalah produk utama ekonomi sawit. Nisbah jumlah pengeluaran produk tersebut kepada jumlah pengeluaran bahan kering akan memberi gambaran indeks tuaian, manakala nisbah berat tandan kering kepada pengeluaran bahan kering akan memberi gambaran indeks tandan. Pertamanya, kegunaan asimilasi adalah untuk pertumbuhan vegetatif, sekiranya ada lebihan barulah digunakan untuk pengeluaran tandan. Kuantum 'lebihan' tandan yang akan dihasilkan adalah bergantung pada alam sekitar dan muatan tandan dalam pusingan dalaman pokok sawit. Pengeluaran bahan kering vegetatif berbeza mengikut kesuburan tanah, pendebungaan, dan sebagainya, dan akan memberi kesan kepada hasil. Pertimbangan seterusnya ialah kandungan

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tenaga dalam bahan kering di mana minyak mengandungi lebih tenaga berbanding dengan bahan bukan minyak. Minyak mewakili hanya 40% daripada bahan kering dalam tandan tetapi mempunyai lebih 60% kandungan tenaga. Oleh itu, kefahaman di dalam proses fisiologi dalam pembahagian asimilasi adalah perlu untuk meramalkan hasil.

Bagi meramalkan hasil, kefahaman mengenai perbezaan seks bunga adalah diperlukan. Kertas kerja ini memberikan kaitan utama antara hasil dan hujan sebelumnya sejajar dengan pelbagai proses fisiologi yang berlaku pada masa itu. Oleh kerana hasil sawit sangat sensitif kepada tegasan air, jarak hujan yang panjang boleh digunakan untuk membuat ramalan hasil dalam jangka masa panjang sehingga dua tahun. Untuk jangka masa pendek antara 6 hingga 12 bulan, kaedah Ulu Bernam dan ARIMA digunakan.

Akhir sekali, selari dengan kemungkinan menerima guna pertanian teliti, maklumat awal fisiologi tanaman mesti dibekalkan oleh satelit bagi meramalkan hasil untuk kawasan yang luas, contohnya, sebuah estet, wilayah atau negeri. Daripada gambaran satelit, satu kaedah boleh diperolehi untuk membezakan tegasan fisiologi yang dialami oleh tanaman dan seterusnya potensi hasil kawasan itu boleh ditentukan. Anggaran hasil tanaman dan mungkin juga hasil kemuncak dan melawas boleh dikaitkan dengan pemerhatian ladang supaya gambaran satelit boleh digunakan untuk meramalkan hasil di peringkat nasional. Dengan memperolehi sistem meramal hasil sedemikian dan bersama dengan maklumat pengeluaran sebenar sedia ada akan membuka jalan ke arah industri sawit berasaskan maklumat.

ABSTRACT

As the oil palm industry stands poised to enter the 21st century, it is an appropriate time to take stock of the lessons learned in the first 100 years of the crop in Malaysia. The end of the century is not just time to look at Y2K compliance for the new century, but, more importantly, to assess the three Ps – (yield) potential, production and prediction – in order to allow the oil palm industry to progress further. In the assessment, however, it must be borne in mind that what is good in the past may not necessarily be so for the future.

During the past century, significant improvements in the actual and potential yield have been made through breeding by crossing outstanding individuals. More recently, biotechnology has been invoked. While breeding in oil palm is largely focused on the development of pest and disease resistance, the new tool of biotechnology has the scope for not only increasing yield but also to modify the product (oil) quality. Raising the yield potential must be accompanied by an effort to achieve it and good oil quality to boost by using a proven management plan in a systems approach. Many management factors impinge on yield and oil quality like, for example, variety, planting density, earliness, soil fertility, site, fruiting patterns, pest and disease control, maintenance and harvesting, milling and storage. Perhaps the most important of all is plant variety. Each of the factors must be examined holistically so that it can be addressed independently. It is important to remember that each of them can, individually and severally, affect the yield and quality of oil and, therefore, the crop value and profitability.

In the new millennium, planting oil palm solely for its oil may not hold anymore as fibre from its biomass becomes important for composites. Research on oil palm should therefore focus on its total productivity as both the oil and biomass would be economic products. Its 'productivity' will then be the total dry matter produced and what is important will be the energy harnessed to produce this. Oil palm productivity depends on three factors - the incident solar energy, the fraction of solar energy intercepted by the crop canopy and the efficiency of conversion of the intercepted radiation into dry matter. If the two economic products have different values, then the dry matter partitioning into them will also be important. Each of the four factors (three + partitioning) are examined for a better understanding of their roles in contributing to yield.

Currently, palm oil and palm kernel oil are the economic products of oil palm. Their combined production expressed as a ratio to the total dry matter production gives the harvest index while the ratio of bunch dry weight to total dry matter production is the bunch index. As assimilate is first required for vegetative growth, only the surplus is given to bunch production. The quantum of 'overflow' for bunch production is dependent on both the environment and bunch load in the endogenous palm cycle. The vegetative dry matter production can vary with soil fertility, pollination, etc., *and the yield thereby affected. A further consideration is the energy content in the dry matter as the oil contains much more energy than non-oily matter. Oil represents only 40% of the dry matter in the bunch but over 60% of its energy. An understanding of the physiological processes in partitioning is therefore necessary to predict the yield.*

To predict yield, an understanding of floral sex differentiation is required. This paper gives the major correlations found between yield and rainfall at various times earlier corresponding to the different physiological processes then occurring. As oil palm yield is sensitive to water stress, the rainfall in these broad lag periods are used in long term yield prediction of up to two years. For shorter periods of 6 to 12 months, the Ulu Bernam and ARIMA methods are used.

Finally, in line with the likely future adoption of precision agriculture, physiological knowledge on the crop must be supplemented by satellite reconnaissance to predict yield over larger areas, e.g. *a whole estate, region or even the country. From satellite images, a means should be found to discern the physiological stresses suffered by the crop and the yield potential of the site arrived at. The estimates of crop yield and, if possible, the peaks and troughs as well, should be correlated with ground observation so that satellite reconnaissance can be used to predict the national yield. Deriving such a yield forecasting system, together with the actual production knowledge already available, will pave the way towards a knowledge-based oil palm industry.*

INTRODUCTION

Over the past 100 years, much progress has been made in improving the oil palm yield in Malaysia. The Malaysian oil palm industry's success is one of the outstanding achievements that has yet to be emulated by any other crop or country. Today, many developing tropical countries are trying to emulate the Malaysian success for their own socio-economic development.

With over 3.08 million hectares of oil palm in the country at the end of 1998, the large supply of palm oil available has enabled many downstream activities to be taken, a boon to its economic development. For example, as a source of edible oil, it has fully satisfied the national needs – an achievement environmentally well done as well! With the world population expected to grow 2% a year, the 1998 supply of oils and fats at 102 million tonnes will have to become 136 million tonnes by 2015. This hefty increase of 34 million tonnes will require all the 17 major oils and fats to play their part, and Malaysia with its small population and large palm oil production an inordinately large part. This is an impetus for the oil palm industry the world over to produce more oil. From 14% of the world production of oils and fats in 1980, palm oil has already increased its share to 17% in 1998 and is expected to equal the soyabean oil share of 21% by 2010. In terms of export, palm oil will continue to lead with its world market share growing from the present 33% to about 40% by 2020.

Besides supplying the food industry, palm oil has also begotten the Malaysian oleochemicals industry, currently supplying 20% of the world demand for oleochemicals. Another recent development is the biocomposites industry where fibre from oil palm biomass is used to make components for Proton, the national car.

In the future, another 'industry' in the making may be carbon sequestration - the trading of carbon offsets. With global warming from carbon dioxide emissions, credits may be given to sequesters of carbon which may be sold to emitters. As oil palm is a net sequester of carbon, it should earn credits and income for the country. It is expected that by 2008, carbon trading will become a reality.

Thus, the oil palm can earn revenues in four ways which must be maximized, all the more reason to improve plantation management with increased R & D to solve the myriad problems in the field. But even as the hitherto mono productive crop gives way to a multi productive one, the central theme remains the same – that for the earnings from food, oleochemicals, biocomposites and carbon sequestration to be maximized, the crop yield of oil and fibre must be improved.

The objective of this paper is, firstly, to explain the issues involved and review the work on them, and, secondly, to propose avenues of research to meet the challenges in the new millennium. The aim is simply to fully use the knowledge already available to raise the crop yield.

PHYSIOLOGICAL BASIS FOR YIELD

The physiological basis for yield must first be understood before steps can be taken to raise the actual yield to closer to that of the potential. The yield potential is set by the genetics of the crop and the site characteristics.

The Importance of Breeding in the Yield Potential

At the onset, due recognition must be given to the breeders who have significantly improved crop yield by crossing the best palms to obtain superior progenies (Jalani, 1998). The potential yield is now estimated to be 18.5 t ha^{-1} yr^{-1} oil-thanks to the vast gene pool now available in the country. In recent years, from ca. the early 1980s, a new and powerful tool – biotechnology has been harnessed to boost the progress in crop improvement. Although the current effort in biotechnology is mainly to produce palms resistant to pests and diseases, the tool, in general, allows for the creation of advantageous new genetic combinations to express desirable traits, including higher yield.

Thus, the major goal of plant breeding and biotechnology can be to maximize yield with subsidiary characteristics like disease resistance and tolerance to environmental stress incorporated whenever possible and necessary. Besides these, the oil(s) produced can be modified, *e.g.* speciality oils with unusual fatty acids. This may be followed by protein modification to increase the contents of certain amino acids, carbohydrate modification and, finally, an attempt to increase the high value minor components. This avenue for quick crop improvement is now actively pursued.

The advent of plant biotechnology will certainly have implications for the agricultural, food and non-food industries. An obvious benefit will be the ability to produce premium speciality products. Another would be the potential consolidation of the nutraceutical and pharmaceutical industries from the production of vitamins A and E, as minor components in palm oil, for the food industry. Thus, plant biotechnology, as an adjunct to traditional plant breeding, is able, firstly, to introduce new traits with specific benefits, and, secondly, to do so in a selective, precise and controlled manner. Breeding will remain a vital tool for crop improvement as it complements genetic engineering since transgenes would have to be incorporated back into the host palms with a desirable genetic background for them to be expressed.

Further development in this young field of research will depend on the industry's efforts to overcome the many technical challenges and socio-economic constraints, such as the requirement for funding, relatively long time for the results to be commercially exploitable, venture risks, intellectual property rights, safety, legislation and consumer acceptance. Given the emphasis on oil palm genomics in the Eighth Malaysia Plan, it is conceivable that plant biotechnology will play a major role in raising the oil palm yield in the 21st century.

The Gap between Actual and Potential Yield

The potential crop yield is defined as the possible yield free of constraints, *i.e.* the potential genetic yield without environmental limitations. Corley (1983) estimated the value for oil palm to be 17 t ha^{-1} yr^{-1} oil, arriving at the figure by using the maximum rate of daily dry matter production subtracted for maintenance respiration and a harvest index (bunch index x oil/bunch) of 36%, based on the best oil/bunch ratio. The figure was subsequently raised to 18.5 t ha^{-1} yr^{-1} *(Table 1).*

The gap between actual and potential yield

TABLE 1. GAPS BETWEEN ACTUAL AND POTENTIAL OIL YIELD

Yield category	Oil yield ($t\ ha^{-1}\ yr^{-1}$)	Gap ($t\ ha^{-1}\ yr^{-1}$)
Yield potential	18.5	
		6.0
Best progeny	12.5	
		7.0
Good commercial estate	5.5	
		1.8
National average	3.7	

occurs because of limiting factors. For example, some yield is lost through water stress and nutrient deficiency. It is therefore important to identify the limiting factors at a site and ameliorate them wherever possible.

Even without further advances in genetic manipulation, the oil palm industry already has a lot to do to realize the yield potential. There is a 7 $t\ ha^{-1}\ yr^{-1}$ oil yield difference between the best progeny and good commercial estate yield. Efforts to minimize the site limiting factors, *e.g.* soil conservation and mulching to ameliorate water stress, must be accompanied by management efforts against yield loss factors like pests and diseases and inadequate fertilizer application.

UNDERSTANDING OIL PALM PRODUCTIVITY

Dry Matter Production, Yield and Biomass

In the past, the emphasis in breeding has been to increase the oil and kernel yield as both were the only economic products from the palm. But as the industry forges ahead and finds uses for its other products, the total productivity of the palm may have to be considered. Both palm oil and palm kernel oil together constitute less than 10% of the crop biomass produced leaving the bulk to waste. The question begged is whether this bulk can be used.

With the advent of the biocomposites industry, oil palm fibre from its various parts - trunks, fronds and empty bunches – is increasingly used in the manufacture of parts for the national car, Proton. As a potential use for the biomass has emerged, it is useful to review and understand oil palm productivity *in toto*.

To the planter, 'productivity' is the fresh fruit bunches (FFB) or oil produced. This is dependent on the total amount of dry matter produced from the solar radiation received, and the amount partitioned into the bunches. Many useful ratios have been derived to analyse the process (Corley *et al.*, 1971a, b; Squire and Corley, 1987). For example, the ratio of palm and kernel oils (PO + PKO) over total dry matter (TDM) is the harvest index (HI), and the weight of FFB (dry weight) to TDM is the bunch index (BI). Thus, HI is BI x (oil/ bunch dry weight + kernel/bunch dry weight).

The production of crop yield (*Y*) from solar energy is the result of four processes - solar energy (*S*) incident on the canopy, the fraction (*f*) of solar energy intercepted by the canopy, the efficiency (*e*) of conversion of the intercepted light into dry matter, and the dry matter partitioned (*p*) into the economic products of oil and kernel. Thus,

$$\text{Yield } (Y) = S \times f \times e \times p$$

In oil palm, the assimilate requirement for vegetative growth takes precedence over that for bunch production. Thus, only the 'surplus' to growth is used for bunch production. Despite its priority, vegetative dry matter production is not constant but varies with the soil and its fertility (Corley and Mok, 1972; Breure, 1982; Squire; 1985), ablation, pollination and planting density (Corley, 1973; Corley and Breure, 1992).

In estimating the yield potential of a site, the factors limiting *S*, *f*, *e* and *p* need to be assessed. Without going into detail, it suffices to say that:

- The incident solar radiation (*S*) on an area depends on its day length (in turn dependant on the latitude and season) and irregularly with altitude and short term weather conditions like cloudiness. The (*S*) is therefore a function of site location and cloudiness.

- The extent to which the canopy intercepts solar radiation, or fractional interception (*f*), depends not only on the leaf area per unit land area (leaf area index) but also on the canopy characteristics like leaf angle and the arrangement of leaves, *i.e.* canopy structure or architecture. The variation in (*f*) accounts for most of the differences in yield between sites and different parts of the year or season. Thus, canopy development is important and care must be taken to ensure that there is no loss in leaf area caused, for example, by pest and disease attack. Hence (*f*) is basically dependent on the leaf area index and foliar extinction coefficient.

- The photosynthetic efficiency (*e*) varies less than (*f*). The (*e*) is influenced by the relative rate of photorespiration which is for building up of dry matter while maintenance respiration consumes assimilates. Variations in environmental factors will influence (*e*). Therefore, increased production can come from an increase in (*e*). In other words, (*e*) is influenced by the relative rates of net photosynthesis and respiration and by the spatial distribution of photosynthetically-active radiation (PAR) within the canopy which affects total photosynthesis.

- The partitioning of dry matter (*p*) to FFB is the least understood of the four factors as very little is known about the mechanism controlling the allocation of dry matter to the various competing sinks, *i.e.* leaves, roots, stem, maintenance respiration of mature tissue, defence against stress and diseases. The situation is made more complex when the FFB itself is partitioned into oil and non-oily matter. Thus, the harvest index, *i.e.* the net result of (*p*) is an important characteristic, and it has to be increased in breeding to produce palms with a higher yield potential.

From the above discussion, raising the yield potential will require physiological research into three options:

- Increasing (*p*) while maintaining total dry matter production;
- Maintaining (*p*) but increasing total dry matter production; and
- Increasing both (*p*) and total dry matter production.

To explore the options, it is useful to first search the literature despite the little quantitative information on partitioning. The values of (*p*) reported for bunch production vary between 0.4 to 0.6 based on above-ground dry matter production (Corley *et al.*, 1971a; Corley and Breure, 1981). These figures would need to be verified as already a figure of as high as 0.73 has been reported based on total energy. Arguably, (*p*) should not be based on dry matter but on energy (Henson, 1997). Another aspect is to consider the below-ground biomass, *i.e.* roots, which have been little studied. The energy and below-ground biomass are discussed further.

Energy Content in Oil and Non-oily Vegetative Dry Matter

An important point to remember from earlier is that oil palm vegetative growth takes precedence over reproductive growth. The newer simulation models have subtracted the vegetative dry matter production (VDMP) from total dry matter production (TDMP) to obtain an improved bunch dry matter production (BDMP), or yield (van Kraalingen *et al.*, 1989). However, prior measurement of the VDMP is required. Previously, to assess productivity, the FFB was converted to dry weight by multiplying by 0.53, its approximate dry matter content. This must be recalculated to allow for the higher energy content of oil in the bunch (Squire, 1985). Because of the different energies in the dry matter components, it makes more sense to partition assimilates in terms of energy than in dry matter content. As oil contains about 2.1 times more energy than VDM, about 1.4 times more photosynthate is needed to form BDM than VDM (Squire, 1985; Squire and Corley, 1987). Hence, the maximum HI of 0.34

dry matter by Corley (1983) for oil palm becomes 0.52 if energy is taken into consideration.

The energy content has been used to recalculate the non-oil equivalent dry mass from Corley and Lee (1992) and Wood and Corley (1993). The value obtained was 19.3 kJ g^{-1} for the bunch frame, mesocarp fibre and kernel fibre while shell contained 25 kJ g^{-1}. For kernel and mesocarp oils, the values of 38.2 and 39.0 kJ g^{-1} were obtained.

Henson (1997) drew attention to the problems of assessing oil palm productivity over periods of less than one year – bunch production cannot be considered as the bunches harvested in a particular month as they would have formed over several months prior to harvest. Further, the higher energy content of the bunches vis-á-vis the vegetative tissues would require the bunch non-oil equivalent dry mater production (NOBDMP) to be recalculated for each month. Tracking NOBDMP throughout the year would enable new studies to understand the regulation and causes of seasonal yield variation.

Further, as oil plus kernel yield of oil palm is a product of TDMP, NOBDMP, BI and (O/B + K/B), the question to ask is to what extent have yield improvements derived from genetic versus environmental advances. Squire (1985), in an analysis of data from various experiments done throughout Malaysia from 1975 to 1980, found TDMP not to have changed much but bunch yield (FFB) increased by 36%, representing a higher partitioning of assimilates into bunches. Reviewing the work of Henson and Chai (1998) and Lamade and Setyo (1996), it is found that consideration should be made for both biomass and energy content.

Associated with the stability of TDMP, Henson (1997), recalculating the figures of Squire (1985), showed that the value of e^*, (the radiation use efficiency based on non-oily dry matter) was also stable.

In another study, Henson (1997), using the figures of Lee *et al.* (1990), showed a reduction in VDMP accompanied by marked increases in NOBDMP, PO production and BI. However, there were also increases in non-oily total above-ground dry matter production, e^* and TDMP.

Thus, there is a need to do long term breeding and physiological trials together to determine the mechanism of partitioning based on varietal differences so as to improve the final yield potential of oil and biomass.

Biomass Distribution, Production, Productivity and Turnover in Roots

Besides the often-studied above-ground biomass, the below-ground biomass, *i.e.* roots, deserve more attention. Most of the studies done so far have ignored the root system as there is no simple and rapid non-destructive method for assessing it (Chan, 1997) as compared with the methods developed for above-ground measurements (Hardon *et al.*, 1969; Corley *et al.*, 1971b; Corley and Breure, 1981). Early destructive measurement of oil palm standing biomass in Malaysia suggested that roots comprise only a small faction of the total biomass (Corley *et al*, 1971a). This has led roots to be taken as only a minor and constant fraction of total biomass (Breure, 1988), and root constants have been used in modelling oil palm growth (van Kraalingen, 1985; van Kraalingen *et al.*, 1989). More recent work in East Africa, however, has shown the root system to take over 36% of the assimilates (Dufrence, 1989; Dufrence *et al.*, 1990). This means that much more work needs be done to clarify the situation.

MAIN FACTORS AFFECTING PRODUCTIVITY

Sunshine and Rainfall

Based on knowledge of the above processes, it is possible to draw a flow chart of the physiological yield formation process (*Figure 1*).

The main climatic factors affecting oil palm productivity are sunshine and rainfall. The optimum conditions are a minimum temperature of 22°C – 24°C, maximum temperature of 29°C – 33°C, evenly distributed rainfall of above 2000 mm yr^{-1} and sunshine of five or more hours a day.

Floral Inflorescence Dissection

Because of the long time from initial formation to bunch harvest, very little is known about

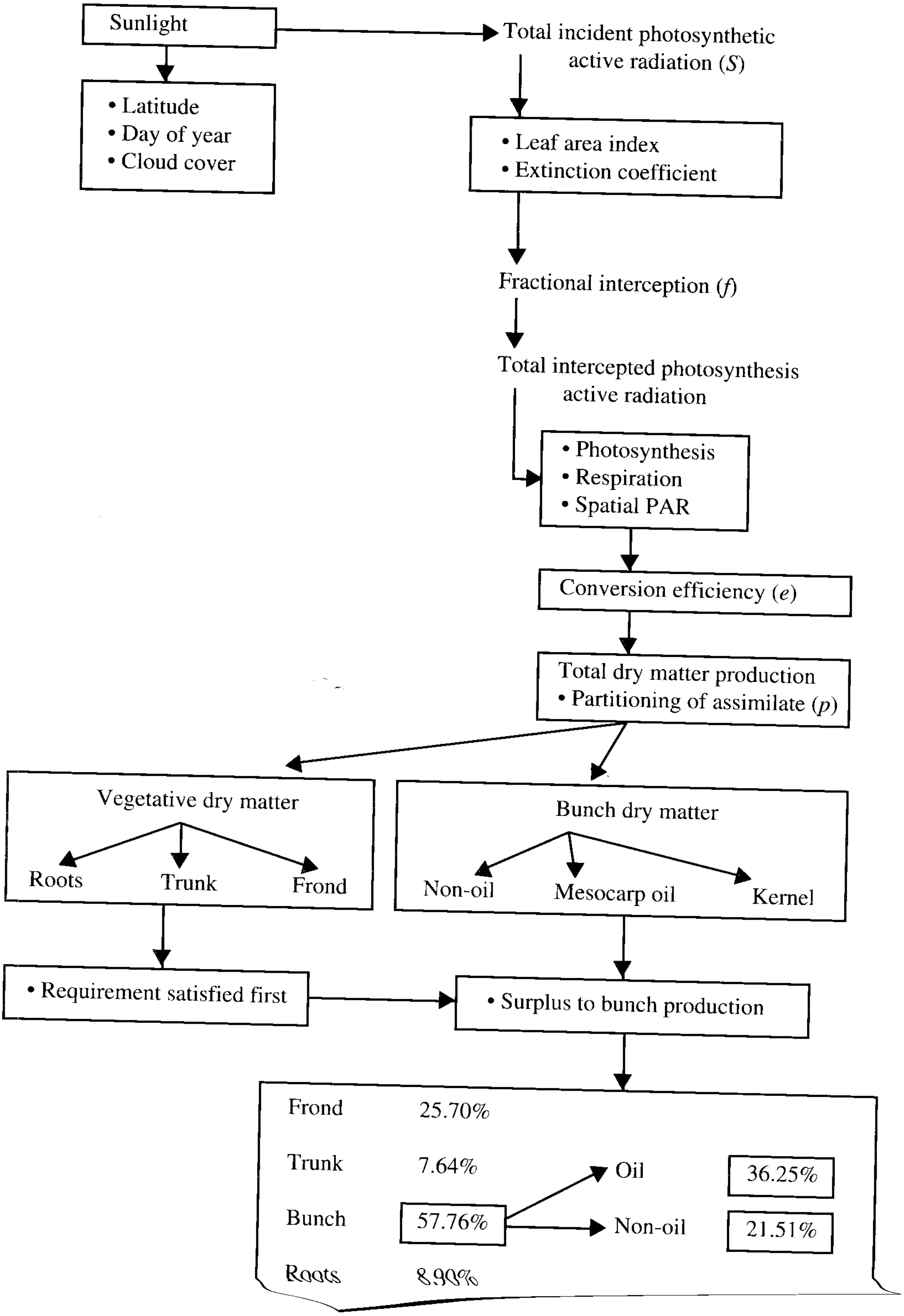


Figure 1. Physiological process of yield formation.

floral development and bunch formation. But by dissecting over 120 eight-year-old palms, the various stages of floral development have been identified *(Figure 2).*

Generally, the earliest frond initiated is about -50 to -52 (relative to Frond 1, the youngest fully-opened frond). Inflorescence initiation occurs at Frond -48 to -50, outer spathe initiation at Frond -38 to -40 and inner spathe initiation at Frond -30 to -32. Initiation of the first bract occurs at Frond -24 to -26 and the fourth at Frond -18 to -21. Spikelet formation is at Frond -8 to -10, spikelet differentiation at Frond 0 to 1, abortion at Frond 9 to 11, anthesis at Frond 17 to 19 and frond senescence at Frond 48.

These general periods of inflorescence development are very similar to those found by Corley (1976) and van Heel *et al.* (1976). It is important to understand the sex differentiation and inflorescence abortion and a description can be found in Corley (1976). However, much work is still required to understand the environmental control of sex differentiation. Generally, the first bract stage is when the sex is visibly determined.

Yield Prediction

Numerous attempts have been made to devise a reliable yield prediction method. For short term prediction, the simplest method is to count the number of black bunches. As the bunch

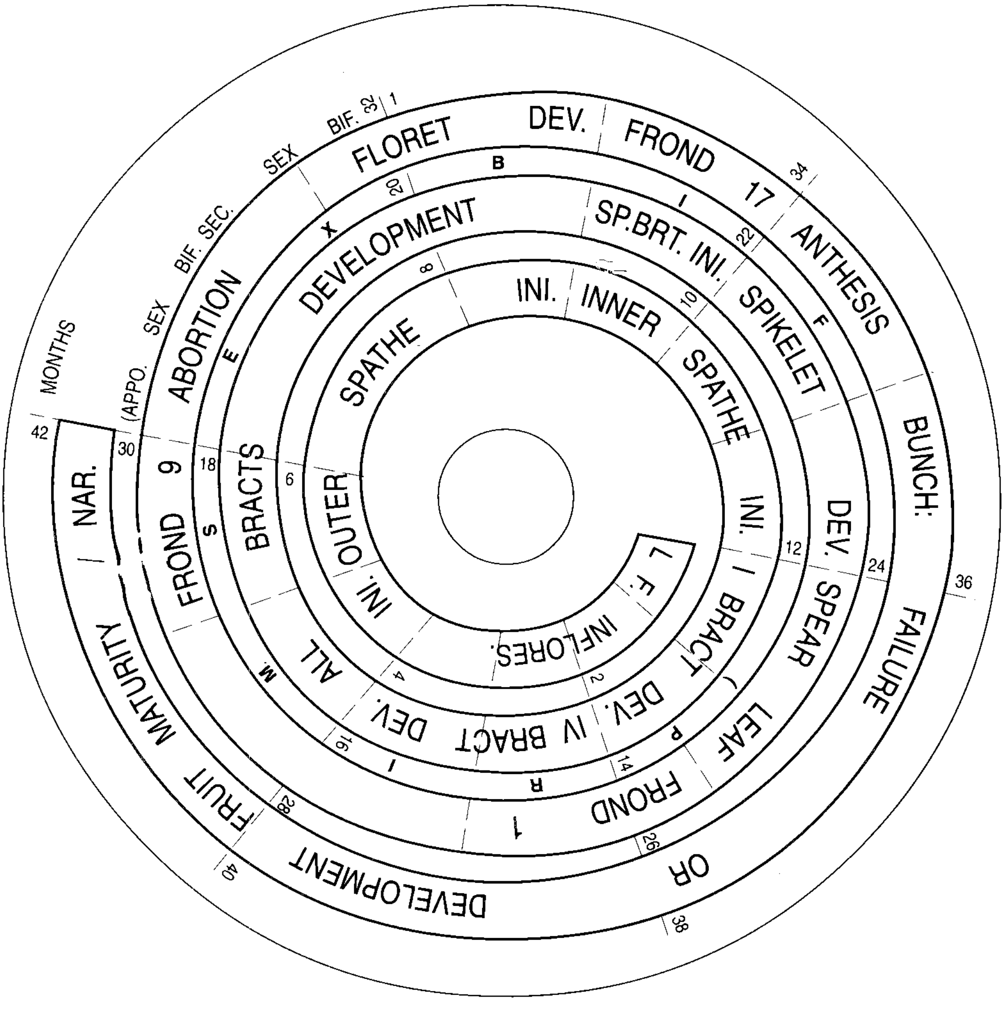


Figure 2. Floral sex differentiation.

weight varies little compared to the number of bunches produced, this would provide a reasonable estimate of yield several months later. Some of the methods used are ARIMA and Ulu Bernam the United Plantations' (UP) black bunch count, both equally good in precision. For predicting over five months ahead, the relationships between yield and climatic factors are used. The successful methods used are with effective sunshine in Africa (Sparnaaij *et al.*, 1963) and rainfall in Malaysia (Chan *et al.*, 1985).

Effective sunshine is basically an index of the effect of moisture stress on sex differentiation (number of bunches formed) to yield some two years later. It has been used to predict annual yield successfully in Nigeria (Purvis, 1973).

In studying the effect of rainfall, positive correlations have been found between yield and rainfall 0, 10 -12, 22 - 24, 35 - 36 and 46 - 47 months earlier, and negative correlations with rainfall 5 - 7, 14 - 18 and 29 - 32 months earlier (Chan *et al.*, 1985). These correlations and knowledge on inflorescence development have been successfully used to predict seasonal yield, inclusive of its peaks and troughs, up to two years ahead.

The correlations between yield and rainfall (both positive and negative) are shown in *Figure 3*.

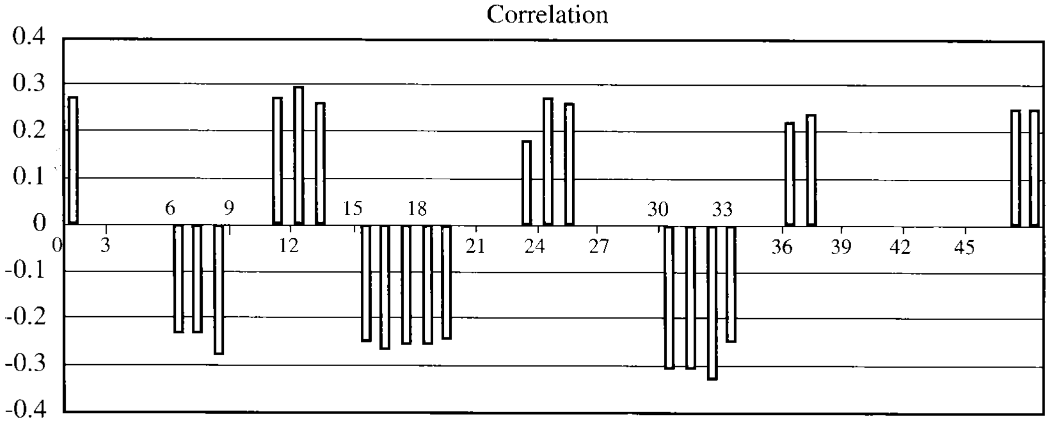
Generally, rainfall at anthesis will reduce pollination, resulting in a lower yield (negative correlation) six months later. The positive correlation between rainfall and yield 10 months later is due to reduced abortion, and the negative correlation 15 to 16 months later is the effect of low rainfall causing more male infloresences. Rainfall is also positively correlated with yield 22 to 24 months later due to more female infloresence differentiation, and the negative correlation at 29 to 31 months is due to the converse - high male infloresence initiation. Positive correlations are also found at 34 to 36 months (preferential female infloresence initiation) and 46 to 47 months (promotion of inflorescence primordial growth).

However, the longer the time lag from rainfall to its purported effect, the less precise is the correlation.

Effect of Fertilizer on Yield

As VDM production is sensitive to the crop nutritional status (Corley and Mok, 1972), it is a useful parameter with which to compare fertilizer treatments. Site specific fertilization is the objective of crop management. To develop the practice, the soil is tested in grids to assess its nutrient-supplying capacity. An important aspect is to interpret the soil test results vis-à-vis the cultural practice to evolve a system to maintain the soil fertility. The approach should be agronomically sound and the most profitable over time.

In oil palm, knowledge of the root system



Source: Chan *et al.* (1985).

Figure 3. Correlation between rainfall and yield at various months (0 to 48) before harvest (only significant correlations were plotted).

is still rudimentary. For example, it is not known if the root system increases with yield. If not, and shoot growth exceeds root growth as the yield rises, higher nutrient uptake by the roots is needed. Factors that increase the shoot:root ratio would increase the N, P, K and Mg requirements for the plant as well as the water needed. Thus, there is great need to study the distribution of roots in the soil for nutrient uptake. Unless the nutrient and water requirements for root growth are known, the fertilizer requirement for a site would be difficult to predict from its yield alone.

Thus, a new approach should be used to assess fertilizer effects. Soil tests should be developed for specific soils, crop ages, cultural practices, and dry matter produced distributed between the above- and below-ground parts, and between yield and non-oily vegetative parts. One way to improve site specific yield is to draw up plots on a soil map from sampling an area. Target yields for the individual plots can be estimated from the differential fertilizer rates required. The plots, as marked in a GPS, can be put into a GIS with paired yields 'without' and 'with' fertilizer at different levels, and the data used to derive a relationship between soil fertility and yield for the particular plots.

Site Specific Yield and Use of Satellite Images for Yield Estimation

Over several years, yield and fertilizer data can be compared to satellite images of the crop to determine the factors that influence fertilizer response besides soil fertility. For example, at the ground, there will be a higher K requirement if there is no empty fruit bunch mulching, and certain coastal soils, especially on Selangor series soils, do not require much K fertilizer. The information obtained will form a good basis for fertilizer management. The longer the ground observations, the more accurate will be the prediction of yield and fertilizer recommendation, improving the return on investment in using satellite images.

Unless this is done, the yield potential of the site cannot be quickly determined. Knowing the potential yield, the economic value of changing the actual yield can be estimated. Such research into nutrient management aimed at realizing the full yield potential and optimizing the profitability of individual sites should be done.

In line with the adoption of precision agriculture, estimating potential yield over larger areas of a whole region or country is a must. Images taken by satellites, like Landsat, Spot, *etc.* of oil palm growing areas must be correlated with the yield obtained and soil fertility to relate the images to yield. The work is preliminary, and more funding should be provided so that satellite earth observations can be used for national yield prediction.

Evolving the Production-based Oil Palm Economy into a Knowledge-based One

The knowledge gained in estimating the yield potential, production and its prediction must start the process to evolve the oil palm cultivation to a knowledge-based industry from its present production base. The advances made in information and communication technology (ICT) will facilitate this. The challenge lies in maximizing the benefits from understanding dry matter production, partitioning of assimilates to oil and non-oily components, its effects on sex differentiation *etc.*, and, at the same time, to reduce the possible adverse environmental impacts of growing the crop. This will depend on using precision agriculture, such as satellite images to estimate maximum crop yield from soil fertility and the capacity of the oil palm industry to assimilate ICT technology. Only when this is done will the techno-economic advantages for the oil palm industry be realized.

CONCLUSION

As the oil palm industry moves into the new millennium, it should learn from the lessons of the last century. The philosopher, George Santayana, once remarked that 'those who cannot remember the past are condemmed to repeat it. But those who learn from it move on successfully, guided by the added perspective of hindsight. They profit tremendously from the lesson of their earlier setbacks because they take pains not to repeat the same mistake nor take the same old trodden path'.

We do not wish for the oil palm industry to continue to rely on the yield only seen on the palms but to be able to forecast it, using ICT, in a knowledge-based economy, further ahead. Science and technology will play a greater role in raising the yield potential, narrow down the production gap and provide us with advanced and accurate yield prediction. This is our vision for the oil palm industry.

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