PORIM INFORMS: An Innovative Fertilizer Organizational Management System for Oil Palm in the New Millennium

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ABSTRACT

In the new millennium, as Malaysia marches on to achieve its Vision 2020 of being a developed nation, the oil palm industry is playing its part by modernizing itself. As with all businesses, adoption of advanced technologies, that contribute to greater efficiency and higher productivity, will provide the producers with the competitive edge over those who continue to remain in their more traditional path. To meet the challenges of the changing need of the industry, better utilization of new technologies such as global positioning systems (GPS), geographic information systems (GIS) and variable rate technologies (VRT) together with advances in information and communication technologies (ICT) are heralding in the knowledge (K)-based economy into the oil palm industry.

Producers are now giving greater emphasis on the knowledge required in the exploitation of the specific characteristics of the planting materials, soils and climatic resources. Further, the knowledge of fertilizer input use efficiency through proper zone, frequency, timing and method of application together with nutrient balance in relation to soil nutrient supply, crop removal and reduced nutrient losses from the agroecosystems are used in their effort to achieve maximum exploitation of site yield potential (MESYP). With the use of the modern technologies such as GPS, GIS, VRT and ICT in concert, producers have moved MESYP forward by phasing out whole field from being treated as homogenous units for application with the same rate of fertilizers and by focusing on precision agriculture based on management of several site-specific units within a field for variable rates of fertilizer application.

Producers by doing so can now capitalize on the spatial variability of the soils within a field and manage the field as a collection of many smaller site-specific units which can now be optimally cared for. This innovative approach, called PORIM INFORMS is an acronym of the INnovative Fertilizer ORganizational Management System for quick monitoring and application of inputs at specific sites within a field. The expected gains are improved productivity, competitive edge, cost saving and a concommitant regulation of the ecosystem. Further INFORMS in complementing sustainable practices will propel the plantation industry to be among the leaders in the K-based economy in Malaysia especially in the effort in globalization of palm oil in the world oils and fats market.

ABSTRAK

Dalam alaf baru, sedang Malaysia bergerak ke arah mencapai Wawasan 2020 untuk membentuk negara maju, industri sawit memainkan peranan penting dalam memodenkan industri ini. Sepertimana juga dengan lain-lain perniagaan, penerimaanguna teknologi terkini oleh pengeluar akan menyumbang ke arah kecekapan dan produktiviti yang lebih tinggi dan ini akan memberi kelebihan daya saing berbanding dengan mereka yang masih terus dengan cara tradisi. Dalam menghadapi cabaran keperluan industri yang berubah, penggunaan teknologi baru seperti sistem kedudukan global [global positioning systems (GPS)], *sistem maklumat geografi* [geographical information system (GIS)], *teknologi pelbagai kadar* [variable rate technologies (VRT)] *bersama dengan kemajuan dalam teknologi informasi dan komunikasi melambangkan ekonomi*

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berasaskan maklumat (k-ekonomi) dalam industri sawit.

Pada masa kini, pengeluar telah memberi penekanan yang lebih kepada maklumat yang diperlukan dalam mengeksploitasi ciri-ciri tertentu untuk bahan tanaman, sumber tanah dan cuaca. Seterusnya, maklumat penggunaan input baja yang cekap melalui zon yang betul, frekuensi, masa dan kaedah pembajaan bersama dengan keseimbangan nutrien dan kaitannya dengan pembekalan nutrien oleh tanah, penuaian buah dan pengurangan nutrien daripada agroekosistem telah digunakan dalam usaha mereka mencapai maximum exploitation of site yield potential (MESYP). *Dengan menggunakan teknologi moden seperti GPS, GIS, VRT dan, informasi dan komunikasi secara bersama, pengeluar telah dapat menganjak MESYP ke hadapan. Ini dilakukan dengan memfokus kepada pertanian tepat berasaskan kepada pengurusan banyak unit-unit setempat dalam satu ladang dengan pelbagai kadar penggunaan baja dan telah membuang anggapan ladang sebagai unit yang sama dan mendapat kadar baja sama rata.*

Dengan berbuat demikian, pengeluar boleh mengambil kesempatan daripada perbezaan tanah dalam sesuatu ladang dengan menguruskan ladang tersebut sebagai kumpulan unit setempat di mana ia boleh dijaga dengan lebih optimum. Pendekatan inovatif ini dipanggil PORIM INFORMS iaitu singkatan kepada Innovative Fertilizer Organizational Management System *untuk memantau dengan cepat dan membekalkan input baja kepada unit setempat dalam ladang. Keuntungan yang dijangka ialah peningkatan produktiviti, daya saing, pengurangan kos dan regulasi ekosistem. Seterusnya, dalam melengkapkan amalan mampan, INFORMS juga akan melonjakkan industri perladangan sawit di kalangan peneraju dalam k-ekonomi di Malaysia terutamanya dalam usaha globalisasi minyak sawit dalam pasaran minyak dan lelemak dunia.*

INTRODUCTION

The 1999 production of palm oil at 10.5 million tonnes coming from 2.70 million hectares of mature palms out of 3.10 million hectares planted, has attained an improved national oil yield of 3.88 t ha^{-1}. Such an increase is due both, to a recovery from the drought-related effects of the 1997 *El Nino* depression and the increased use of multidisciplinary interplay of the best developed practices as in MESYP to provide optimal production. The 1999 production, despite larger hectarage, outyielded the 1998 and 1997 productions of 3.27 and 3.68 t oil ha^{-1} respectively.

For some time now, it is recognized that the revolution in ICT and an accompaniment of the worldwide process of deregulation, have helped herald in the K-based economy which has emerged as one of the essential factors in the global market of oils and fats. At the same time, ICT has helped in tracking the considerable advances that have been achieved in several areas of the various components of the MESYP concept. Such advances, when incorporated have helped to revolutionize the monitoring of crop growth and production of both the above- and below-ground biomass in terms of both weight increases and energy content. The rise in K-based economy is increasingly recognized as a vital raw resource for economic growth and wealth generation. It has provided a new economic framework for the oil palm industry to modernize itself. For example, in marketing where with globalization and trade liberalization, the international competition of palm oil trade has dictated the use of ICT to get better cost savings in business transactions and increased efficiency in the firm's value-added change. Likewise with the fast electronic computing power to recall the advances made in the field of manuring and fertilizer management, the K-based economy has helped refine the systems approach on manuring. There is now a distinct use of the characteristics of planting materials, soils, climate, nutrient and water dynamics to construct a more innovative approach to measure real life situations in the manuring process. This means that the industry, in starting the process of incorporation and utilization of advanced knowledge through the rapid recall from the store of voluminous accumulation of information to link with the use of modern technologies such as GPS, GIS and VRT, will enhance the K-based economy. In other words, greater knowledge use is introduced into the production and in all the economic activities involving both goods and services. Thus, the arrival of the K-based economy has posed many new challenges to the oil palm industry. They range from the process of knowledge generation through R&D till their utilization and application in production centres and in the market place.

This paper urges the producers to grasp the changes that are happening and devise policy changes, both within individual organizations and nationally as an industry, to respond to meet the challenges accordingly. Hence, this paper will identify the present advances made in the field of planting material, soils, climate, manuring and fertilizer management for incorporation into the systems approach of MESYP; and secondly, with the knowledge gained propose to move MESYP forward through MPOB model of INFORMS by focusing on the use of precision agriculture to shift the management of whole field from being treated as a homogeneous block for fertilizer application to management of many site-specific units with different fertilizer requirements to exploit spatial variability, thereby increasing productivity of the whole field.

ADVANCES MADE IN K-BASED IN THE FIELD OF MANURING

From the producers' point of view, in the new millennium, nutrient management has become sophisticated and complex. It is part of the sustainable high yielding crop production system. In light of the advances made in the K-based that ranges from R&D findings, to economic pressures and increasing public concerns about plantation agriculture's impact on the environment, the producers' basic skills and technical education have to be improved markedly. They are to provide a broad base knowledge necessary to meet the fast paced changing business environment of a K-based economy as demanded in recent years. New technologies are now available that enable the producers to monitor production systems precisely by controlling application rates and to time the production of outputs. To meet these challenges in a fast changing K-based industry, better utilization of the new technologies is called for. The producers are learning to combine the specific characteristics of planting materials, soils, climate and nutrient sources with the advances in ICT, GPS, GIS and VRT to capitalize on the soil variability within fields to improve the nutrient management systems and productivity. Basically, manuring is an important part of the necessary technologies that are used to sustain a high yielding crop production system.

Interplay of Factors in a Multi-disciplinary System

Manuring continues to be the single largest cost item in oil palm cultivation forming about 65% of the mature cultivation cost (Chan and Yusof, 1998). Current estimate of mature cultivation cost ranges from RM 650 to RM 750 ha^{-1}. Proper fertilizer management is therefore vital to attain efficient uptake, high yield and maximum benefits from the high expenditure on fertilizers. High yields in a crop production system will depend on the right choice of planting material, climate, correct identification of soil types, correct fertilizer types, frequency of fertilizer application, placement and timing. All these factors are used to project the maximum potential yield of the field. Fundamentally, in MESYP, there is firstly, a need to know the limitations posed by the crop defining factors such as poor planting material, low rainfall, poor soil type, steep terrain by minimizing their effects. Next is to eliminate the effects of yield limiting factors such as nutrient deficiencies; and thirdly, occasionally remove the yield reducing factors such as pests and disease infestations as and when such outbreaks occur. The need to raise oil yield per hectare therefore requires the use of the systems approach to fertilizers management where both, FFB and oil yield and their relationships to nutrition of the palms are examined holistically (Chan, 1998; 1999a). Holistically, there are five steps consisting of firstly, procurement and distribution of fertilizers from the supplier to the plantation; secondly, the prediction of site yield potential based on the natural resources of climate, soil and planting material; thirdly, the actual site-specific nutrient management system itself; fourthly, the need for extension and education, particularly to the smallholders; and fifthly, the economic evaluation of the value of each fertilizer input to the value of the crop output.

The systems approach of looking simultaneously at many variables in fertilizer use efficiency is not new. The whole system as a model has been given initially as in PORIM Technology Bulletin No. 13 (Foster *et al.*, 1986). A similar system was also described by Ng and Thong (1985). The systems approach was also applied by Chew *et al.* (1992) and Foster (1993); as INFERS (Integrated site-specific fertilizer recommendation system) by Kee *et al.* (1994) and Goh *et al.* (1994) and refined as PORIM OPENS (oil palm efficient nutrient system) by Tarmizi *et al.* (1999) and Chan (1999a). Basically, the emphasis of these modern crop production systems is the need for sustainable development (Chew *et al.*, 1994; Chan, 1995a, b; 1997; Pushparajah, 1998)

Invariably, the common parameters used in the model for prediction of site yield potential consist of planting material, soil, site (field) and climatic considerations. The INFERS and PORIM OPENS are systems which include the nutrient balance concept built into the yield target calculation of the site yield potential production for each block on an estate (Kee *et al.*, 1997; Tarmizi *et al.*, 1999). The additional consideration is to ensure that factors that influence nutrient demand and supply are integrated into the agronomic as well as site-specific characteristics of the field. The fertilizers recommendations that follow will become more objective, scientific and consistent to sustain high yields (Goh *et al.*, 1994).

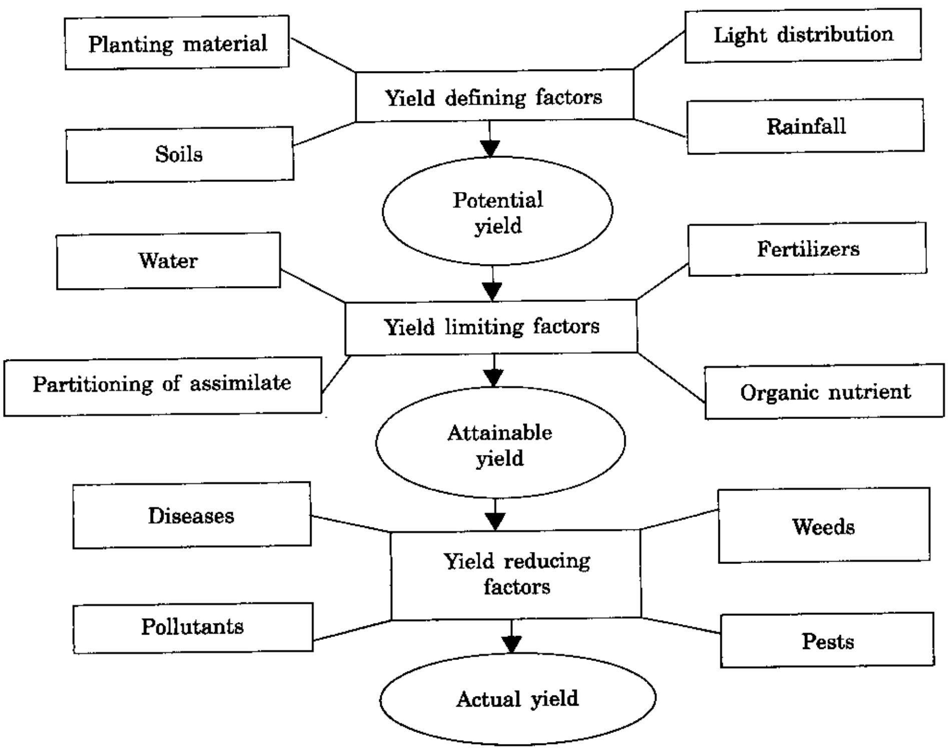
The site yield potential is defined as the largest yield obtainable when all environmental conditions and agronomic practices are optimal for the full genetic potential of the type of planting material to be expressed. Hence, factors determining site yield potential as shown in *Figure 1* are as follows:

From *Figure 1*, it immediately dawns on the producers that there are long term detailed information gathering, evaluation and assessment of many variables listed above. This, as pointed by Chew *et al.* (1998), is only possible for large plantation companies with in-house R&D or advisory facilities. This is because for each individual field, the time and work in assessing the variables are tremendous. Fortunately, MPOB has embarked on a task to extend the systems approach through PORIM OPENS to these producers who are interested to use this modern crop production system. At all times, the components of the system are constantly reviewed and upgraded under major headings as follows:

Planting Materials

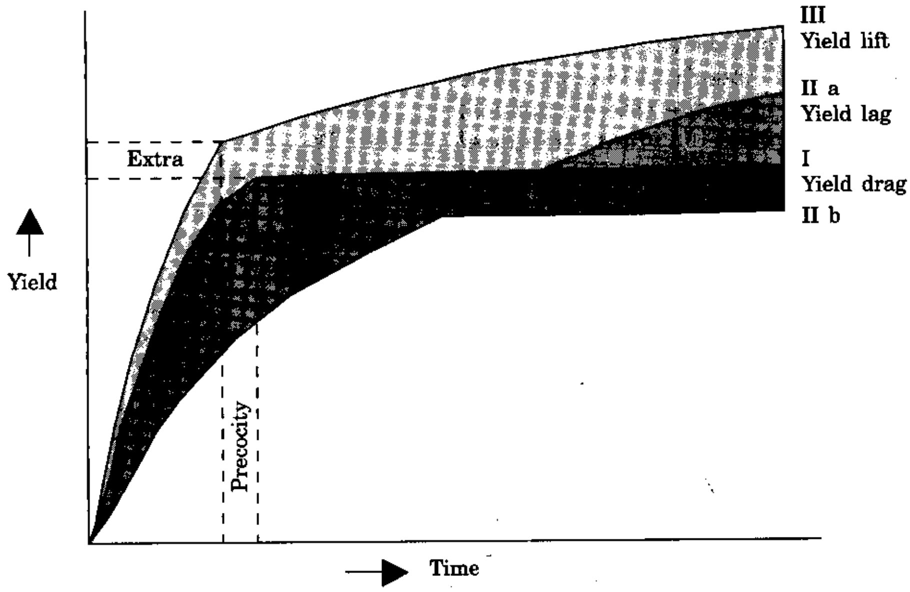
The oil palm industry is always upgrading its planting material which is produced by more than 12 major seed agencies in Malaysia. The new planting material now includes those from conventional breeding and plant biotechnology (Rajanaidu *et al.*, 1999). Generally, the pattern of yield can be divided into the three graphs as shown in *Figure 2*.

Presently, most of the clonal palms, due to their abnormality, have about 20% of them studied in trials to have yields higher than the current commercial planting material from conventional seed material (Cochard *et al.*, 1999). This will result in two situations: firstly, of yield drag (situation IIa) where the yield



Source: Chan (1999a).

Figure 1. Production situations as influenced by yield defining, limiting and reducing factors.



Keys

I = Present planting material.
II (a) = New material with no chance of exceeding current material (yield drag).
II (b) = New material with possibility of exceeding current material only at later stage (yield lag).
III = New planting material with improvement in precocity and high yield (yield lift).

Figure 2. Diagrammatic representation of yield drag, lag and lift in relation to the breeding and biotechnology efforts built into new planting material as compared with current planting material.

remains lower than the current commercial material; and secondly, the material may exceed the current commercial material but only at the later stages of production giving an overall lower total yield as in situation (IIb). This represents yield lag. Finally, what is hoped for in any breeding material development is that it will result in yield being better than the current material (*i.e.*) yield lift with gain in both early maturity through precocity and attainment of high plateau yield.

Though yield lag can be improved by additional breeding cycles or tightening up the biotech procedures, both will require additional investments to improve. Most breeding stations are pursuing this approach as both biotech and breeding research are key projects to improve yield potential. Even though yield drag is often seen in transgenic palms, it cannot be over emphasized that more test planting of such transgenic palms is still required to be carried out by research stations because such test evaluations are required to determine any change in oil composition and to test whether recloning of high yielding palms will work. For the former, this may still lead to new products that may offset the slightly lower yield penalty caused by yield drag or yield lag, and for the latter, new high yielding planting material is possible from recloning. The future of breeding and biotechnology lie in increasing yield potential though new high yielding planting material and development of specialty oils.

After the breeding and selection of the best planting material and ensuring that they are planted well, the large part of the research effort is to get the best interaction between the palms with the soil and fertilizers. Looking at the soil first, effort into the study of soil must ultimately be directed at optimal production and effective input of fertilizer into each specific site.

Soils

Soils, as medium of growth, is also a source of moisture and nutrients. A good understanding of its constituents is essential so that correct mineral fertilizers are added to them. One needs to know how much of the added nutrients are retained and made available to the palms and how can the uptake be used for maximized growth and yield? Generally, soils are a function of climate, relief, organisms/vegetation, parent material and time. Climate, in terms of temperature and moisture, influences the type of organisms and vegetation.

Relief allows the rain to run off the surface and where there is no soil conservation, severe erosion of soils will result. Shallow soils improvement will depend on the rate of chemical weathering taking place. Parent material influences the texture and some chemical properties. For example, basalts give rise to soils rich in iron while granites give soils with low free iron oxides. All these weathering will be influenced and modified with time, especially on the leaching of nutrients.

The value in classifying soils is to understand the soil characteristics in relationship to the soil properties and for the provision of a sound basis for extrapolation of information in the natural soil system. For example, the advantage of using soil information from soil survey to plantation tree crops has been demonstrated by Ng and Selvadurai (1967) and Ng (1984). A better understanding of the soil nutrients as a limiting factor to plantation crops could be detected with some chemical properties analysed at various horizons (Law and Tan, 1973). This has been extended to trials when analyses of chemical properties of a series of 50 completed experiments from the industry was done (Foster *et al.,* 1985). Based on the chemical analysis, the nutrients as affected by rainfall, lack of soil conservation measures and delay in fertilizer arrival for application were soon considered as contributing factors to spatial variations when assessing the soil as one of the major resources for the MESYP. There is a need to refine this under the MESYP model which has considered the whole field as a homogenous block for fertilizer application. This treatment of whole field as a homogenous block has been in existence since Ng and Thong (1985) first conceived the MESYP concept and but there should be variation in fertilizer recommendation to exploit spatial variability within a soil type (Foster and Tarmizi, 1989).

Some ten years later, based on good research results done on the spatial soil variability in fertility and on the impact of continuous application of fertilizers in palm circles on soil pH, as presented by Goh *et al.* (1995), results indeed showed that whole fields should not be regarded as a homogenous block for fertilizer application. Results further confirmed that maximum variances of soil properties were reached at about 2 m and within this distance, soil pH and exchangeable cations showed strong spatial correlations where 57% to 86% of the variances were found respectively in the microsite. There were negative variances found between soil pH, exchangeable cations and base-saturation. It was also shown that long term fertilizer application in palm circle has caused pronounced acidification with a greater risk of leaching of K, and a higher N and K run off. To maintain nutrient uptake efficiency, Goh *et al.* (1995) proposed the application of fertilizers in palm circles be made only during the younger stage but this gradually should be extended to the interrows when the palms are more than ten years old and the canopy had closed. Wherever possible, application should be avoided during high rainfall periods and also onto harvesting paths as soil fertility measurement shows that the status is highest under frond piles.

Another consideration is on how the land is used during the immature period either simultaneously or sequentially for intercropping. In view of the time sequence, the fertilizer management between immature and mature phases need to be revised. This has often been overlooked especially with regards to the history of the previous cropping. There are further requirements of space constraint during the immature phase where cash cropping including that of cattle rearing is practised. The various possible combinations of previous crop history are as shown in *Figure 3.*

From *Figure 3*, there must be a distinction made between the above-ground land use in the four quadrats and their effects on the below-ground resource use during the simultaneous and sequential systems. In sequential systems, all biological interactions occur via soil conditions in the physical, chemical, and biological fertility aspects. In ex-jungle and ex-secondary forest, sufficient nutrient reserves are available for oil palm roots to act as nutrient pumps to bring the nutrients up to the surface and deposit them either as leaf pruning or empty fruit bunches (EFB) after processing. Once on the surface, nutrient availability will depend on the rate of mineralization of the pruned fronds or EFB to release the nutrients and on the root development under frond piles to extract the nutrients.

The difference between ex-jungle and ex-secondary forest is seen not just on the amount of debris left behind in both situations on the surface since zero burning has been enforced, but on the below-ground biomass based on the root density of the previous crop. The presence of large amount of debris, both above- and below-ground, will influence nutrient management. If the clearing for planting is on ex-problem soils areas such as peat, shallow acid sulphate, saline,

	Stages	Previous crop history	Immature	Mature
Space	Replant	Ex problem soils	Oil palm	Oil palm
		Ex oil palm: o 3rd replant o 2nd replant o 1st replant	Oil palm + cash crop	Oil palm
		Ex rubber Ex cocoa	Oil palm + cash crop	Oil palm
	New clearing	Ex problem soils Ex primary jungle Ex secondary jungle	Oil palm Oil palm Oil palm + cash crop	Oil palm Oil palm Oil palm
		Sequential	Simultaneous	
		Time		

Figure 3. Classification of cropping history with degree of overlap in space and time.

shallow laterite, podsol or spodsols, and sandy (quartzipsamments) soils, then physical properties rather than nutrient requirements are given greater attention. To these problem, soil groups may be added the emerging group of calcareous soils such as Langkawi series from limestone in Kedah or Semporna series derived from sea shell in Sabah. For these problem soils, oil palm is planted during both the immature and mature stages without any intercropping being practised and this applies also to their period of replanting where no intercropping is encouraged. Therefore depending on the history of replants and whether intercropping is practised, the nutrient requirements will differ according.

As for the management of the problem soils such as peat and shallow acid sulphate, maintenance of water table is crucial which mainly is practised to prevent irreversible shrinkage in peat and exposure of the jarosite layer to oxidation in shallow acid sulphate soils respectively. Peat also has micro nutrient deficiencies problems particularly of Cu, Zn and B. As for saline soils, following construction of main bunds, there must be drains made to allow constant flushing and leaching of salts to less than 1000 µmhos cm^{-1} for desirable palm growth and yield. As for shallow laterite, the low effective soil volume will result in low nutrient status and water holding capacity. Besides physical limitation of a hard pan, there is low CEC and high P fixation in laterite soils. There is also a need to maintain desirable ground vegetation and to build up organic matter. Maintenance of water tables in podsol, spodsols and sandy soils will help reduce water stress which other wise will cause yield to decline.

From the above description, there is a need to go deeper than from just a simple broad mapping of soils within a field. One has to go into details on the physical characterization to describe colour, texture, horizonation and profile development; chemical characterization of clay content, iron content, cation exchange capacity, trace element content and exchangeable cations; and for mineralogy characterization such as types of clay minerals. All these characteristractions must be made with both space and time sequence in mind as discussed in *Figure 3*. This provides new angles to look into for efficient fertilizer management for which they have largely been ignored in the past. With systems approach, the challenging task is to quantify and explore the range of cropping options to improve the fertilizer management system. For example, nutrient re-cycling through mulching will add on another dimension when considering fertilizer use efficiency. The knowledge and information of these various aspects will be just as important. In an effort to achieve high sustainable crop production, many standard manurial schedules during nursery, immature, early mature, mature and period prior to replanting must be considered. Therefore in the new millennium, the spatial variability of the soils due to soil types, mapping, land use, cropping pattern, sampling intensity and manurial practices should be exploited and nutrient deficiencies overcome by using VRT.

Influence of Climate such as Rainfall and Light Distribution on Oil Palm Physiological Efficiency of Nutrient Use for Growth and Development

Nutrient uptake and its partitioning into yield are very much influenced by the partitioning of assimilate into different parts of the oil palm such as partitioning into leaves, bunches, trunk and roots. Based on a review of work of Squire (1985), Lamade and Setyo (1996), Henson and Chai (1997), and Chan (1999b), it is possible to construct a partitioning of assimilate based on biomass and energy requirements of the various parts as shown in *Table 1.*

From *Table 1*, it is important to note that in the oil palm vegetative growth takes precedence over reproductive growth. Thus when constructing simulation models, the total dry matter production is used to subtract the vegetative dry matter production to determine the bunch dry matter production (bunch index) so that the FFB yield derived in this way can be used to represent an improved yield estimate. Prior to this, the productivity assessment is done simply by using the monthly FFB yield as converted to dry weight by multiplying with the ratio of FFB by a factor of 53% (Corley *et al.*, 1971).

The new FFB recalculation will allow the higher energy content of mesocarp oil in the bunch to be determined. As a result of this new approach in calculating differently the partitioning of assimilate into FFB in terms of energy rather than biomass weight, the harvest index (HI) based on bunch index x oil/bunch as quoted by Corley (1983) at 0.34 is now changed to 0.52 when equated in terms of energy content.

It is only through this energy consideration that Henson and Chai (1998) showed that the direct use of bunch harvest data collected on a monthly basis is inadequate to represent seasonal production. Since much of the dry matter for bunch production may have been formed prior to the month of harvest. Thus, irrespective whether energy or just dry matter biomass is used to calculate non-oil bunch dry matter production, attention must be given to the physiological efficiency on nutrient use. This is because energy, dry matter and nutrient uptake are indirectly measured by the assimilates partitioned to vegetative growth first and then to yield. So to understand the fertilizer requirements following peaks and troughs in production, the vegetative growth and seasonal yield patterns must be recorded.

The subject of physiological efficiency has been studied by Fairhurst (1999) and it is an internal utilization efficiency of the applied nutrients going into the yield increase. The additional yield obtained with fertilizer has been calculated using this physiological efficiency. However, Fairhurst formula is based on the above-ground dry weight measurement. It would be better if the energy content of oil which is about twice that of non-oil biomass and the below-ground biomass of roots are factored into the equation of physiological efficiency. The product of physiological efficiency and recovery efficiency, the latter representing the uptake efficiency, will give a better measure of the

TABLE 1. PARTITIONING OF ASSIMILATES INTO DIFFERENT PARTS OF OIL PALM BOTH ABOVE- AND BELOW-GROUND DRY MATTER BASED ON BIOMASS AND ENERGY CONTENT IN PERCENTAGES

	Parts of palm	Biomass %			Energy %		
Above-ground	Leaf	20			14		
	Infloresence	60	Non-oil	25	43	Non-oil	18
			Oil	35		Oil	25
	Trunk	10					
Below-ground	Roots	10			36		
	Total	100			100		

Sources: Chan (1999b).
Squire (1985).
Lamade and Setyo (1996).
Henson and Chai (1997).

agronomic efficiency.

The distribution of roots in a soil profile, the root growth according to fertilizer application, soil type and frond pile have been studied using the trenching or auger methods by Talliez (1971), Chan (1977), Tan (1973), Goh and Amit (1993), Henson and Chai (1997) and Cuesta *et al.* (1997). For better quantification of root growth and turnover, minirhizotron has been constructed by MPOB to study the below-ground biomass.

The vegetative dry matter requirement has not been given prominence in the past. As vegetative dry matter requirement is itself not a constant but vary with soil type and fertility (Corley and Mok, 1972), more work is required in the field to understand the particular aspect of partitioning of assimilate to vegetative growth in various soils. If less assimilate is partitioned to vegetative growth, then more will be diverted to yield. The effect of applied nutrients on the partitioning of dry matter into both oil and non-oil biomass within the bunches themselves are now being looked into in greater detail. A better understanding will give rise to enhanced capabilities to raise yield potential.

Fertilizer and Nutrient Sources

The influence of fertilizers on manuring, growth and yield of oil palm has been critically reviewed with the use of several aids like foliar analysis, foliar symptoms, soil analysis, cultural practices, environmental and climatic factors, vegetative growth measurements, yield levels and their responses from various fertilizer trials (Chan, 1992). From the detailed analyses of these aids, it is clear that there is indeed a physiological requirement of fertilizers where at high levels of manuring, leaf N and K plateau off while yield continues to increase. P and Mg are required, though at lower rate for the full expression of N and K on yield. The effects of each fertilizer nutrients of N, P, K and Mg from 67 completed trials conducted on inland soils by one major plantation company have been summarized in the papers by Chan and Rajaratnam (1977) on Mg, Chan (1981a) on N, Chan (1981b) on K and Chan (1981c) on P.

From the results, N and K nutrients had been found to be synergistic on growth and yield. They increased leaf area and net assimilation rate. K besides affecting growth and yield also influenced the extraction rate by lowering it but because of the higher yield of fruit bunches, larger overall total oil yield was achieved. P was found to have long residual effects lasting up to four years while K and Mg had residual effects lasting for two years and N had shortest residual effect of one year. All these findings were found on trials that were conducted using the direct application of mineral fertilizers alone without any emphasis on the use of other alternative nutrient sources in combination.

During the mid 1970s up to the end of 1980s, there was a shift towards the use of legumes and by-products from the palm oil mills and rubber factories as alternative nutrient sources. Based on the findings, legumes besides providing N for replacement of N fertilizers, also improved soil physical properties. Better growth and increases in yield were observed even after the legumes had died out. The findings on the use of EFB and palm oil mill effluent (POME) on yield increases have helped the wider use of these by-products to replace the use of mineral fertilizers in palms. Other benefits of early maturity and reduction of environmental impact from use of by-products such as EFB at their time of planting were highlighted.

Efficient fertilizer use in oil palm requiring the integrated use of mineral fertilizers with these by-products were also highlighted (Chan *et al.*, 1991; 1992; 1993). The details of these investigations provided valuable information and knowledge for studying the effects of efficiency of fertilizer application in terms of interactions with these organic by-products. The effects investigated included application of N and K fertilizers applied in the presence and absence of mulching with EFB, frond placement as piles versus frond spreading, method of application in the weeded circle as against broadcast at different frequencies of three and six times a year. All these results showed that efficiency of fertilizer usage can be improved, especially with the use of residues which are rich in organic matter. Besides allowing for reduction in fertilizer inputs through the synergistic interactions, it also encourages the nutrient recyling of residues as on soil properties improvement reported by Khalid *et al.* (1996; 1997).

The important findings from these trials were that new interactions such as N x mulching, K x mulching are now exploited to obtain higher yields. All these advances in fertilizer efficiency have been implemented by the industry to increase yield and reduced costs.

For the future, fertilizer use efficiency, which indicates an output/input ratio, will require the boundaries of these inputs and outputs to be spelt out so that they are measured correctly. For example, fertilizer use efficiency in the context of estate is taken to mean the various components of the estate by-products used in the estate as fertilizer substitutes. It includes the use of both mineral fertilizers and the use of recycled plant biomass and their interactions.

Thus, agronomic efficiency of fertilizer usage is always assessed by splitting it into three measures of:

(i) Application efficiency (available/input);
(ii) Uptake efficiency (uptake/available); and
(iii) Utilization efficiency (product, FFB and oil/uptake).

All three measures can be quantified annually.

Fertilizer Efficiency in Relationship to Labour Shortage

Efficient use of fertilizer contributes to the economic viability of the oil palm industry. The fate of mineral when applied to the soil is generally complex. By efficient use of fertilizers in the field, it meant getting the fertilizers in the most suitable form and at the most appropriate time to the palms without unnecessary losses. There are generally five ways in which fertilizers applied in the field would behave. First, they are taken up by the palms. Secondly, they become part of the soil complex. Thirdly, they are leached downwards through the soil into the drainage water. Fourthly, they can be physically washed away by surface erosion. Fifthly, they can volatilize and escape as a gas.

Understanding these five ways on how fertilizer would behave becomes an important first step in relating efficient fertilizer use in overcoming nutritional problems and to increase yield. Each of these steps has been studied. For example, to improve the amount of fertilizers taken up by the palms, correct quantities of fertilizers are applied to the active root zones as found under the frond pile. To minimize the amount of fertilizers from becoming part of the soil complex, legumes, EFB, POME and pruned fronds together with their organic matter are used to improve uptake of inorganic fertilizers when applied together. The organic matter also prevents leaching of fertilizers. Proper timing and frequency of application have been practised to reduce leaching losses. The spreading of pruned fronds across harvesting paths and across the slope of the field along the contour can help prevent the physical wash by surface erosion of the fertilizers applied. Example of this type of fertilizer wash is that of rock phosphate which is not water soluble. To reduce volatilization, choice of fertilizer type is important, for example, the use of sulphate of ammonia as against urea is preferred as the latter can volatilize and escape as a gas into the atmosphere. Lately, the use of interaction effects between organic mulches and mineral fertilizers has helped plantations to improve uptake of mineral fertilizers. They also provide the necessary synergistic interactions on yield improvement.

Unfortunately while efficient fertilizer use is considered at all times on one hand, labour shortage and rising labour cost on the other hand have often sacrificed its efficiency in trying to achieve minimum cost. The three ways of applying fertilizers by manual application, by mechanical spreading and by aerial application have been evaluated by Lim and Chan (1992). Results, as in *Table 2*, showed that mechanical application when compared to either aerial or manual applications, had no significant differences. However, all treatments were significantly better than control.

TABLE 2. EFFECTS OF APPLICATION METHODS OF N AND K FERTILIZERS ON OIL PALM

Application method	Mean FFB (t ha^{-1} yr^{-1})
Tractor mounted spreading	25.24
Hand application	24.43
Aerial application	23.84
Control	18.07
	se ± 0.357

Source: Lim and Chan (1992).

Further, as mechanical spreading is more labour efficient, cheaper and more effective, the use of tractor mounted spreader would allow for correct frequency and timeliness of fertilizer application thereby achieving fertilizer use efficiency under labour short situations.

To improve the preciseness, tractors mounted with spreaders should be fitted with radio receivers and computers which can update their positions as frequently as possible. The hopper of the spreader is divided into say five compartments for N, P, K, Mg, B for variable type and rate of fertilizer applications. The real benefit of the system comes from the distribution controllers which record the amount applied as desired at the exact locations as demarcated by the GPS. The advances in use of receivers and computers, and different fertilizer compartments for differential applications have given rise to variable rate techniques (VRT) to exploit soil variability.

USE OF MODERN TECHNOLOGIES TO EXPLOIT SOIL SPATIAL VARIABILITY

To understand soil spatial variability, to better manage the fertilizer application, to maintain soil fertility, to reduce soil losses and to use the soil resources better are some important considerations to raise crops in site-specific fertilizer management (Goh *et al.*, 1994). This is because there is superiority in spatial variably fertilizer management over the current conventional practices that do not seem to harness the wide variations in the soil fertility, and where the whole field receives more or less the same inputs of fertilizers.

Much of the variability is due to differing soil types, natural inherent soil fertility, man's manuring activities, and depending on rainfall, slope and conservation practices, the surface run off and leaching, will add on to the site spatial variation. For example, man's activities in certain areas of high rainfall of 3000–4180 mm over say 139–172 days of rain per year have resulted in subsurface placement of fertilizers in the attempts to reduce surface wash by run off and to reduce leaching. This needs to be evaluated further.

So far, all the work on MESYP has considered the whole field as a single homogenous block for site-specific application of the same fertilizer rate. Generally, fields cover about 20 to 35 ha with some slightly smaller or bigger. To maximize productivity, Chew (1997) has suggested the use of the new computers-based GPS and GIS to display the spatial data in the plantation (Tey and Chew, 1997). Successful implementation of site-specific management will rely on plantations treating each soil type, or a grid field as a single management unit. Obviously, as shown by Foster and Tarmizi, (1989) and Goh *et al.* (1995), the presence of soil spatial variability within narrow distances, there must be a shift in the focus. To increase the productivity of the field, there is now an urgent need for research on marking out small units within a field for site-specific management.

PORIM INFORMS

The innovative approach as proposed by MPOB, is to divide the field further into small units of one hectare each in the proposed trial areas. The soil samples are collected within these one hectare sites for analysis. Results of such soil analysis with these one hectare plots are then consolidated so as to recognize the variation in soil N, P, K, Mg and Ca. From here, it is possible to draw up nutrient maps for correlation with leaf nutrient N, P, K, Mg and Ca. When superimposed with the yield which can now be monitored by crop yield controllers and monitors mounted on tractors to record yield electronically based on individual harvests along the harvesting paths or on a row by row basis. Such rapid recording can be transmitted to generate computer-based mapping, soil and leaf nutrient inputs and yield accurately to provide more precise demarcation of specific sites within a field. The concept of managing sites within the same soil within a field will encourage new precision-based plantation practices.

Fertilizers inputs will then be carried out using the tractors mounted spreaders with differential compartments for N, P, K, Mg and B applications. The inputs are monitored based on the correlation of soil and leaf nutrients with yield. The fertilizer spreader with radio receivers and computers can apply the variable rate technology to exploit the spatial soil variability. Their positions can be updated as frequently as required through the GPS and recorded with GIS.

In the past, this type of management is not possible. Experienced managers, who know their fields, are those who go about checking the fields over a number of years. But today, with the labour saving new technologies of GPS, GIS and VRT, innovative managers are beginning to breakaway from the traditional methods that have long shaped their production practices. Precision agriculture is helping managers to move into high tech crop production thereby achieving the MESYP at even higher levels. For example, with the GPS, the tractor mounted spreaders can position themselves and other mechanical equipment and apply the type of fertilizers if and when they are required and at exactly on the same location time after time.

The exact geographic location can now be easily determined at any time as the tractor mounted equipment moves across the field. As GPS can operate on a 24 hr all weather network, it can provide precise navigation to its earthbased computer system within metres of its target. The grid system can also be extended beyond the exploitation of spatial variability of the soil type by considering the field history differences as mentioned earlier and then linked them with the soil grid analysis programme. Only when digitized field maps are combined with grids of similar nutrients levels does the new innovative approach of fertilizer management be possible on a more site-specific basis.

The new innovative approach called PORIM INFORMS is an acronym of the PORIM INnovative Fertilizer ORganizational Management System for oil palm in the new millennium.

Implications of PORIM INFORMS

Basically INFORMS has a number of possible implications. Firstly, the fertilizer rate can be varied with the nutrient map so that the tractor mounted spreader can vary the fertilizer rate either with spot spreading or apply double rate of spreading through electronically controlled monitors. This will replace human labour as presently practised.

Secondly, with the better understanding of the detailed characteristics of the field, the innovative managers can focus the fertilizer applications to overcome nutrient differences, and apply to areas where it is under performing to raise the yield potential.

Thirdly, yield mapping by number of harvesting rounds recorded by management will now give the precise expected in-field variation of each site-specific units in terms of cropping pattern. Thus, over time it will allow for a new database to be built up, particularly on individual specific sites where crop yield at the micro level have not been yield mapped before. From these in-field variation of yield, the whole potential yield of the field will now be accurately mapped. Luckily, as most plantations have past records of field yields collected manually, these historical information, over a long time series, even tracing back beyond the present crop to old rubber or cocoa yield pattern will provide consistent and persistent field information in the whole estate where yields have been low. Thus by bringing the yield mapping system together with historical data, it is possible to unlock hidden information about the causes of variation of individual fields for example with mineral deficiencies, water logging, acidification, *etc.*

Fourthly, yield variation of fields, when analysed on many site-specific units will bring out the potential causes. This may be caused by one or a combination of N, P, K, Mg and Ca balance in the soil and in the leaf as related to natural or fertilizer application practices in the past. By comparison of fertilizer application, soil nutrient and leaf nutrient maps with yield maps, a link between fertilizer application practices and crop yield vigour can be detected. When related to say some fertilizer deficiency, then the yield maps can form the basis for calculating the additional nutrient requirement.

Fifthly and lastly, crop yield could have been suppressed and prevented from realizing their full yield potential through many other factors besides nutrient deficiencies. They can be water-stress induced, yield cycle-pattern related, climatic-effect related (as experienced by the *El Nino* effect of 1997) pest-infestation related, *etc.* Be as it may, a start can now be made to pin point precise areas where site-specific technology can help the innovative managers to practice sound agronomic management profitably and have better responsibility of not to over-fertilize with better environmental and soil stewardship. Ultimately PORIM INFORMS will complement sustainable agriculture in the plantations.

DISCUSSION

With the new innovative approach being spearheaded by PORIM INFORMS, the industry can look forward to better agronomic management of plantations in the future. With the new knowledge and new information and advanced mechanization with computer technology, it is bound to change the way oil palm is grown and manured in the new millennium.

The approach is new and there are still a lot of teething problems but PORIM INFORMS promises a way forward to have a computer program to link MESYP with GPS, GIS, VRT and ICT. There are already many programmes in other crops on water, nutrient and light capture in agro forestry systems. This may be adapted here.

For the future, the job required dictates that the successful manager must also be a K-based worker as the worker has to be adept in handling information planning, supervising, scheduling and managing data. Not only has the worker to do more 'knowledge work' but also has to put in a higher level of knowledge content into the work even in the more traditional economic activity. In fact, the plantation industry of the future requires teams of experts who are superior in skills planning, supervising, scheduling and managing data. Information and knowledge have become the raw material for their work, products and services. The plantation of the future is going to be a K-based organization. There is a need to prepare the industry to understand the new innovative system and its management. Understanding the impact of climatic variability and determining what tactical management to respond to seasonal variations for example will form only a part of the system that will allow for better crop production in the future.

CONCLUSION

With the advent of GPS, GIS, VRT and ICT, the management of plantation, in the new millennium will be K-based and will apply innovative approaches such as PORIM INFORMS to move MESYP forward from treating the field as a homogenous block for same fertilizer application to one that is managing a series of site-specific units with different fertilizer requirements, thereby realizing the full yield potential for a field.

The time is ripe for the plantation industry to use precision agriculture and the labour-saving space age technology for the K-based worker to cover a bigger area yet achieving maximize yield in the plantation. PORIM INFORMS will provide this basic need.

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