Fertilizer Management and Productivity of Oil Palm in Malaysia

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ABSTRACT

Amongst the commercial vegetable oil crops in the world, the oil palm agro-ecosystem produces the largest quantity of edible oil per unit area despite being largely grown on highly weathered tropical soils with low fertility. It is therefore unsurprising that fertilizers and balanced palm nutrition have been pivotal to the well-being of oil palm and the profitability and sustainability of the oil palm industry. The fertilizer management system of oil palm has been established and continuously improved since its large scale plantings in the 1970s. It has served the industry well as evidenced by its sustainability and capacity to weather the regular economic crises. However, oil palms have been expanded to degraded soils, marginal environment and climate. We are now constantly reminded of the stagnating yields and declining competitiveness of the oil palm industry in Malaysia. We need to tap into all resources available and maintain our ingenuity to develop scientifically sound and properly tested practical practices i.e. science-based solutions to overcome difficult challenges and to stay ahead of our competitors.

This paper discusses the various strategies and approaches to ensure effective and efficient fertilizer management in the plantations, and the challenges and future trend in fertilizer management system for sustainable oil palm. We wish to stress that there are no quick fixes for the current economic uncertainty of farming, only good agronomy and management to alleviate its impact on productivity and profitability, and the same is true for the oil palm industry. During this testing time, informed or evidence-based decision is paramount in minimizing agricultural risk because science usually triumphs common sense and personal perception when it really matters.

Keywords: Fertilizer management, fertilizer use efficiency, effective fertilizers, oil palm productivity

INTRODUCTION

In 1992, Chew *et al.* (1994a) surmised that "The growth of the oil palm industry in Malaysia in the last three decades must be one of the great success stories in agriculture". One and a half decade later, it has not only expanded worldwide and increased its area by 104 % but also stamped its success by being the most productive vegetable oil crop, consistent economic returns (export earnings of RM65.2 billion in

2008), large positive impact on local and national social development and adopting environmentally sound and scientifically based practices. The latter has always been the central tenet of our recommended agro-management inputs. We should also note that the above essential contributions of the oil palm industry to our society are also fundamental criteria or guidelines embraced by most definitions of agricultural sustainability e.g. FAO/IBSRAM (Symth and Dumanski, 1993).

The oil palm is quite unlike the other oil crops and probably most agricultural crops in the world, which are mainly grown for domestic markets (Goh and Teo, 2008). The produce from oil palm, on the other hand, is mainly exported and in fact, is the largest traded vegetable oil globally. For example, the global productions of palm oil and soybean oil in 2006 were similar but the global trade of palm oil was nearly three times that of soybean (Figure 1). Today, palm oil is the world largest supplier of vegetable oils and fats, accounting for about 37% of the world's market share. It is the cheapest edible oils (Lam *et al*., 2009) being sold at a huge discount against soybean oil and thus, has been providing affordable edible oils to the masses worldwide. It is probably one of the few if not the only edible oil that can meet the demand generated by the increasing per capita consumption of oils and fats by developing economies and the accelerating world population without excessive use of additional cropland or logged over (degraded) forests (Table 1). In fact, the expansion of oil palm plantings is about 0.5 million ha/yr which is only 4% of total forest loss of approximately 14 million ha/yr worldwide.

These successes have attracted much attention and put the oil palm industry under close scrutiny of international environmental and social non-governmental organisations (NGOs) and agencies, and lately the European Union. Numerous campaigns against the industry have been launched by them which can create negative perception of the industry to the consumers if left unchallenged and unfair trade "barrier" being imposed on us. This is despite the fact that the major oil palm producers have always been responsible planters and subscribed to the concept of sustainability (Chew *et al.*, 1994b) even before the Roundtable for Sustainable Palm Oil (RSPO) was conceived and formed. Nevertheless, many producers will be meeting or have met the principles and criteria of sustainable palm oil as defined by RSPO. Fertilizer management features prominently in Principle 4 of this initiative and certification.

This paper will attempt to relate fertilizer management and productivity of oil palm in the context of current and near future challenges. It is basically an update of our earlier papers on similar subject in particular Chew *et al*. (1994a) and Kee and Goh (2006). We shall also discuss the future trends and needs in fertilizer management of oil palm that may enable us to stay ahead of our competitors and maintain sustainability.

PRODUCTIVITY OF OIL PALM

The rapid growth and high productivity of oil palm have been demonstrated in trials and well managed plantations. Plant breeding trials and physiological computation showed that the potential yield of the oil palm is about 17 t oil/ha (Corley, 1985) whereas over 12 t oil/ha have been reported in small scale breeding trials (Mohd. Din *et al*., 2005) and 6.8 t oil/ha in large commercial plantings (Goh *et al*., 2002) using current DxP materials (Table 2). On average, the clonal planting materials have been shown to have additional 10-15 % oil compared with DxP materials (Soh *et al*., 2003).

Similar results were obtained for fresh fruit bunches (FFB) where consistent high yields in excess of 30 t/ha/yr were reported in numerous trials set-up in the 1970s and 1980s across a wide range of soils and climatic regions (Table 3). Later experiments gave even higher yields for the best treatment plots with many exceeding 35 t/ha/yr (Table 3). These results were reproduced on a commercial scale where Goh *et al.* (1994) using 1960s to 1980s palms illustrated that the more recent plantings not only attained higher yields but also reached peak yields at a younger age than older plantings e.g. 1960s and early 1970s plantings (Figure 2).

The high yields quoted above were mainly taken over a short duration or a point in time, and usually during the peak yielding period. Goh *et al.* (1994) and Chew and Goh (2003) clearly showed that the oil palm exhibits a rapid increase in growth before reaching a plateau at around 10 to 12 years after planting (Figure 3). FFB yields followed suit in tandem with growth but attaining peak yield earlier at between 8 and 10 years after planting (Figure 3). Unlike growth, FFB yields in commercial fields will decline usually 16 years after planting because of increasing difficulty in harvesting and the need to maintain sub-optimal number of fronds for better harvesting efficiency (Goh and Teo, 1997). Thus, the average yield over the productive life cycle of oil palm in each zone (environment) was lower than its peak yield, ranging from 17 t/ha/yr to 29 t/ha/yr (Table 4). This contention is further confirmed by the analysis of 11 private companies with substantial ownership of oil palm plantations covering 1.15 million ha in 2006 accounting for nearly 27.6 % of the total area under oil palm in Malaysia. The results clearly showed that the two best yields were achieved by plantations with high percentage of oil palms in the prime age group or with well distributed palm age whereas the poorest yields were obtained by the four plantations with high percentages of palms due for replanting (Figure 4). Apart from this, every palm in the plantations should be productive (Tam, 1973) for best yield.

Lately, the oil palm has been expanded to more diverse soil types with increasing areas of highly degraded soils, difficult landscape and steep terrain, and marginal climate. This foray partially contributes to the dismal yield improvement since 1980s on a national scale, which is also well illustrated in Figure 4 where companies with larger areas of oil palm have lower mean FFB yields. The use of marginal or unsuitable land for oil palm has imposed additional challenges to the production system, which necessitates the modification of the environment in order to provide the best growing conditions i.e. minimize stresses for high productivity. However, it usually puts unnecessary strains on the system through higher production costs, labour requirements and expertise. Thus, one of the most fundamental pre-requisites in oil palm productivity must surely be careful selection of the site to ensure that the crop is planted on land well suited for it (Kee and Goh, 2006). This will pre-empt much of the current difficulties associated with poor yields, low profitability and sustainability

(Kee and Goh, 2006). In fact, we echoed the call by Teo (2001) and Pushparajah (2002) that further expansion of oil palm areas into marginal or unsuitable land must be strongly discouraged as better alternatives are usually available to enhance profitability and moreover, fertilization cannot overcome all production constraints.

We have also been constantly reminded of the increasing competition from other oil seeds where better yield increments have been achieved between 1970s and 2000s compared with palm oil in Malaysia as shown in Table 5 (Chew and Goh, 2003). Furthermore, the competitiveness of the Malaysian oil palm industry in terms of production costs has also been eroding compared with other oil palm producers (Table 6). Goh *et al.* (2002) have shown that the best remedy or perhaps the most effective solution is to increase productivity per unit area.

Many factors contribute to this high productivity of oil palm, inter alia, improved planting materials, agronomy and management. Davidson (1993) in tracing the progress of palm oil yield in Pamol, Kluang, which was elevated from 1.3 t/ha/yr in 1951 to 5.43 t/ha/yr in 1991 excluding negative factors, listed seven major practices that were responsible for this yield improvement. Amongst them, fertilization was the most important contributor accounting for 29% of the yield increment (Table 7). This was supported by numerous fertilizer response trials conducted in Malaysia, which showed large FFB responses to balanced nutrition (Table 3). Hence, fertilizers not only have the greatest impact on productivity but also commonly constitute the highest operational cost in well run plantations in Malaysia. It plays a pivotal role in the sustainability and profitability of oil palm particularly in recent months when prices of commodities are uncertain and economics of farming has become the dominant issue.

FERTILIZER MANAGEMENT

The rapid growth and high productivity of oil palm as elucidated above come with a cost: the need for high, balanced nutrition that is specific to each site or environment throughout the life cycle of the palms except for the short period before replanting when fertilizer application might be withdrawn. The latter practice is mainly for economic reason. The good responses of oil palm to fertilizer inputs were mainly attributed to the low fertility of highly weathered tropical soils and/or moisture stress (Goh, 2005). The responses can range from less than 10% to over 200% (Table 3). For proper interpretation of fertilizer responses of oil palm, apart from adequate replications and randomisation, at least two other features must be present in the experiments:

a) an absolute control where the tested fertilizers are not applied
b) duration of trial is sufficient to negate all residual effects and avoid premature conclusion

Xavier *et al*. (2008) gave a succinct account of the clear FFB yield responses to fertilizer inputs on relatively fertile coastal soils based on the availability of the above features in their experiments (Figure 5). In contrast to this, it was most unfortunate that recently there were numerous claims on the effectiveness of various new agro-management practices and fertilizers for oil palm plantations. Many of them were inconclusive due to the lack of above features in the “experiments” amongst other weaknesses. Nevertheless, some proponents of such claims have implemented them to the disservice of the industry and such unsound and unscientific practices must be abhorred if the oil palm industry in Malaysia is to remain competitive and sustainable.

Balanced nutrition is also of utmost importance to elicit a response to fertilizer inputs. As shown in Table 8, the maximum FFB yield was obtained in the presence of both N and K. In the absence of N, increasing K rates depressed oil palm yield but had no effect on growth. On the other hand, without K input, increasing N rates had little effect on FFB yields although vegetative growth was significantly improved. Moreover, there are strong indications that where palms were better grown due to proper fertilizer management, the annual yield fluctuations may be reduced substantially (Table 9). This will not only ease the management of oil palms and mills but also the marketing of palm oil.

Therefore, the main objectives of a fertilizer management system are (Goh *et al*., 1999a):

a) To supply each palm with adequate nutrients in balanced proportion to ensure healthy vegetative growth and optimum economic FFB yields.

b) To apply the fertilizers in the prescribed manner over the areas of the estate that are likely to result in the most efficient nutrient uptake.

c) To integrate the use of mineral fertilizers and palm residues.

d) To minimize negative environmental impacts related to over-fertilization, land degradation, and pollution from heavy metals such as cobalt and eutrophism by P application.

These multi-objectives demand that the fertilizer management system for oil palm entails more than just the computation of optimum fertilizer rates although it will always be the first key towards an effective fertilizer programme. The other major components in the system includes correct timing, placement and methods of fertilizer application and right source of fertilizer, recommendation of optimum growing conditions for the oil palm to maximize nutrient uptake, and monitoring of growth, nutrition and yield targets.

Therefore, the fertilizer recommendations seen on the estates, which often appear to be taken for granted, require a good understanding of the general principles governing the mineral nutrition of oil palm (Corley and Tinker, 2003; Goh and Hardter, 2003) and methods to maximize fertilizer use efficiency (Goh *et al.*, 1999a; Goh *et al*,, 2003). It is not the aim of this paper to provide another comprehensive account of the recommended fertilizer management system for oil palm as recently there has been a spate of papers on this very subject matter and the system well described and laid down. Interested readers should refer to Corley and Tinker, 2003, Tang *et al.*, 1999, Goh, 2005, Kee and Goh, 2006 and Goh and Teo, 2008, just to name a few. But for completeness, the key practices in the recommended fertilizer management system are described in brevity.

The nutrient balance method in drawing up the fertilizer rates for oil palm on specific site is now well established (Kee *et al.*, 1994; Corley and Tinker, 2003; Goh, 2005) and need not be elaborated here. Suffice to say that the method requires the following data or information (Goh and Teo, 2008):

a) Data to compute the nutrient balance including expected growth and yield as described earlier.
b) Site yield potential and actual yield
c) Expected response to manuring
d) Assessments of palm sizes, vigour, deficiency symptoms etc
e) Soil data including analysis, soil types, terrain etc
f) Leaf analysis and vegetative growth measurements
g) Factors affecting fertiliser efficiency
h) Palm age, materials, density etc
i) Climatic conditions
j) Field conditions, eg. weeds, drainage, mulching etc
k) Other relevant data, e.g. planting dates, replanting dates, technique of planting etc.
l) Past fertiliser history including fertiliser rates, sources, timing etc

The list of information may appear daunting but with electronic equipment, good database and decision support system, the task of collecting and collating the data is much simpler than thought (Goh and Teo, 2008). It also enables one to significantly utilise the diverse arrays of data for:

a) formulation of fertiliser recommendations
b) judgement of the performances of the palms and estates
c) early recognition of problems and problematic areas
d) building up a knowledge of the fields

which are essential for optimum management, high productivity and lower costs of production, and lately, for RSPO certification.

Also, this comprehensive Integrated Agronomic Management (IAM) system as described by Kee and Goh (2006) has been further combined with database, global positioning system (GPS), geographical information system (GIS), artificial intelligience and 3-D structural-functional model to develop an agronomic information management system (AIMs). Although AIMs is a practical system to provide site specific fertilizer recommendation, much work is still needed to fully validate and perfect it.

Getting the fertilizer rates right is only the first step and one of the key factors in the fertilizer management system. We need to ensure that the fertilizers are appropriately applied according to recommended practices for maximum uptake and utilization by the palms i.e. maximizes fertilizer use efficiency. Therefore, it is essential that the estate management understand and appreciate the major factors controlling it such as timing, frequency, sources, placement and method of fertilizer application even though their impact on FFB yields are usually far lower than optimal fertilizer rates as deliberated below. Since these agro-management practices affect the fertilizer use efficiency, they also influence the production cost and competitiveness of the oil palm industry in Malaysia.

After the optimal fertilizer rates, correct source of fertilizer for the site is probably the next factor with the largest impact on FFB yield responses particularly for N and P. Zin *et al*. (1990) showed that apart from coastal soils, the use of urea would result in lower FFB yields compared with ammonium sulphate treated plots. This was usually attributed to unpredictable N loss via urea volatilization. A re-computation of the data from the above study where only positive FFB yield responses to both urea and ammonium sulphate were considered showed that 14 to 45 % of these responses could be explained by the use of correct N source i.e. ammonium sulphate based on % standardised difference (Table 10). The other common N sources for oil palm i.e. ammonium nitrate and ammonium chloride gave similar FFB yield responses as ammonium sulphate (Lim *et al*., 1982) if fertilizer quality is not an issue.

For fully mature palms, applying N fertilizer outside or within the palm circle gave similar yields. On Briah series soils where there was a 59 % yield response, the different fertilizer placements explained only 8 % of the above yield response (Table 10). Closer results were seen in Durian series soils where yield response to N input was smaller at 24% (results were not presented). Increasing the frequency of fertilizer applications did not result in marked enhancement of FFB yields as expected or assumed by many planters despite the relatively large yield response on Munchong series soils (Table 10). In fact, both placement and frequency of fertilizer applications accounted for less than 20% of the total FFB yield responses; the rest was due to fertilizer rates.

Various methods of fertilizer application have been investigated and again, they differed little at high fertilizer regime (Table 10). However, at lower fertilizer rates, aerial and manual applications were inferior to mechanised application by 13 and 8 %, respectively. This implies that when root contacts with fertilizer are limited, then increasing the concentrations of nutrient will enhance uptake rate provided they are at non toxic level to the roots. A good discourse on this complex subject can be found in Tinker and Leigh (1985) and Tinker and Nye (2000).

Apart from wrong choice of fertilizer for the site, the above results corresponded well with the relatively low nutrient losses of applied fertilizers in well managed oil palm plantations on undulating to rolling terrain. Other methods to minimize nutrient losses on hilly terrain are available as propounded by Ng and Goh (2008).

Lately, sub-soiling the fertilizers especially N and K has been advocated by some plantation companies for various reasons. A close examination of available experimental data and commercial data clearly showed the deficiency of this method of fertilizer applications (Table 11) as expounded by Ng and Goh (2008). Using trial data (Manjit *et al.*, 2002) that met the criteria for proper interpretation as discussed earlier, we found that 27% of the FFB yield response was accounted for by the methods of application. Again, higher fertilizer rate was needed to get a full FFB response. These negative results are well supported or in agreement with current scientific principles of plant nutrient uptake as follows:

a) The amount of roots required for nutrient uptake is proportional to demand or productivity of the plant (Figure 6)
b) Nutrient uptake rate increases proportionally to soil nutrient concentration up to the maximum uptake rate, Vmax (Tinker and Leigh, 1985)
c) Roots are sensitive to excessive soil nutrient concentration (Ng and Goh, 2004) and therefore, any concentrated patches of nutrients must leach out sufficiently before new roots could grow profusely and absorb nutrients (Figure 7)

Also, we need to apply fertilizer at a rate where the soils can hold them for a sufficient period to allow plant roots to absorb most of the nutrients before the next application.

Thus, sub-soiling method should be restricted to areas where management could not control or reduce fertilizer losses e.g. high run-off losses, lack of area to broadcast fertilizers e.g. very narrow terraces, and insufficient satisfactory to fair months to apply fertilizers.

For young palms, the strategy would be to build up the soil nutrient status at the young stage. The AA+ Mulch^{TM} system and FELDA mulch (Figure 8) could be adopted for newly planted palms to reduce the fertilizer application to one round for the first year of planting. In an area with low annual rainfall of approximately 1500 mm per year, initial growth of palms planted with AA+Mulch^{TM} system was superior to those without AA+Mulch^{TM} despite both having the same fertilizer regime (Figure 9). The use of controlled release fertilizers is not necessary with the AA+ Mulch^{TM} system. This was mainly attributed to the drought causing inferior results of the control treatment (without AA+Mulch^{TM}) even at the highest fertilizer rate tested suggesting that in areas with very low rainfall or with high moisture deficits, the AA+Mulch^{TM} system was able to conserve water from surface evaporation. Similar positive results were obtained with FELDA Mulch for one year old palms (Table 12) with subsequent earlier fruiting. The use of controlled release fertilizers is unnecessary with FELDA Mulch. Currently, FELDA has adopted the FELDA Mulch system as a standard practice in large scale replanting of oil palm.

Notably, in the fertilizer management system of oil palm, organic fertilizer in the form of pruned fronds has always been naturally added to the soils. In fact, nutrient release from pruned fronds is rapid and can supply as much as 14% and 24% of the annual N and K requirements of a high yielding mature oil palm field (Kee and Chew, 2006). Apart from this, application of empty fruit bunches (EFB) at 37.5 t/ha/yr would supply all the K and half of the N requirements of oil palm (Figure 10). Also, the impact of EFB on FFB yields was larger on shallow lateritic soils with yield increments ranging from 39 to 53% compared to those on deep Ultisols at between 17 and 29%. Similarly, the other by-products from the palm oil mill such as decanter cake and palm oil mill effluent are excellent sources of organic fertilizers for the oil palm (Lim *et al.*, 1999) and every effort should be made to utilize them fully in view of the current high fertilizer prices, and large energy cost and greenhouse gas emission during the production of most mineral fertilizers especially N.

The estate management also has a vital role to play in the fertilizer management of oil palm and its productivity. The details are provided by Goh *et al*. (1999) and Kee and Goh (2006). Briefly, one of the most critical roles of the estate management is to maintain reasonably uniform manuring block size and accurate manuring block records as described earlier. The manuring block should be relatively uniform in terms of palm age, soils and terrain. For practicality, the block boundaries should be delineated by roads. Thus, as rule of thumb, each manuring block should be approximately 40 ha and at least 80 % uniform. Where there are small distinct areas which require specific treatments e.g. lateritic soils, they should be clearly demarcated and attended to immediately (Kok *et al*., 2000). The area of the manuring block must be accurately measured because all productivity figures and indicators of estate performance are commonly expressed on per unit area basis. These simple procedures are essential to enable the agronomist to provide precise and site-specific recommendations and the estate management to implement them for best results.

The most precise fertilizer recommendations are of little value if they cannot be timely executed and implemented accordingly. Delays in fertilizer delivery, lack of storage or poor storage facility and shortage of workers are common factors causing severe disruption to the manuring programme with consequent poor results (Kee *et al*., 2005). Thus, it is of utmost importance that the estate management and the headquarter ensure that the ordering of fertilizers are promptly carried out, at least three months ahead of delivery to the estates. Fertilizers should always be purchased from consistent, tested, reliable and reputable suppliers of quality fertilizers.

The timing of delivery rate depends on many factors including storage space, estate location and logistics. If possible, “just in time” delivery schedule should be always advocated. Upon delivery, the tonnage and number of bags of fertilizer must be tallied against the purchase order. The use of the estate or mill weighbridge is an absolute must as short weight is fairly common.

There must be a standard operating procedure for testing the quality of fertilizer. SIRIM standards, MS417, part 1, 1994, with a proper sampling tool may be used to sample the fertilizers of each consignment. The sampled fertilizers must be packed appropriately and sent to a reliable laboratory for analysis immediately. The physical properties of the fertilizer should be visually checked at the estate and photographs taken for evidence, if necessary. With the current high fertilizer prices and better fertilizer manufacturing technology, it might be appropriate to impose a higher standard for fertilizer quality than the current SIRIM standards in particular for compound fertilizer and fertilizer mixture. For example, the current 8% variation allowed in the nutrient composition can be capitalized by the suppliers due to its high monetary value.

The fertilizer store must be well ventilated, dry and rainproof (Kee *et al.*, 2005). Upon delivery, the fertilizers should be neatly stacked for easy identification, stock count and efficient reloading and transport to the field for application. This will minimize losses, wastage and cross contamination.

The key procedures in planning and organising fertilizer application in the fields have been outlined by Goh *et al*. (1999), Kee *et al*. (2005) and Goh and Teo (2008). These practical steps have been re-written as standard policy by many plantation companies and interested readers should refer to the above publications for detail.

Good supervision is tantamount and the key to successful implementation of the fertiliser recommendations, be it in manual or mechanised application (Goh *et al*., 1999). The supervisory staff including the managers must walk through the fields particularly in the middle of the field, ravine areas and hilltop areas where mistakes are most common. The importance of close supervision during fertiliser application is underscored in the example provided in Table 13. FFB yield in block 3, which was the nearest to roadside (Row 1 to Row 5), was 327 % above that in block 1 which was the furthest (Row 11 to Row 15) from the road and in the middle of the field. If fertilizers had been evenly applied to the whole field, overall FFB yield would have increased by 52 %.

Kee *et al*. (2005) stressed that apart from palms missed out during manuring or not receiving the prescribed rate in full, the other common mistakes in application include (Goh *et al*., 1999):

a) Application of fertiliser in heaps or narrow bands and application of lumpy fertiliser.

b) Application of fertiliser in wrong areas, e.g. GML in palm circles, N fertiliser in waterlogged spots or on terrace edges.

c) Fertiliser applied too far or too near young palms.

d) Applying fertilisers over the lower fronds in young palms which can result in fertiliser scorch.

e) Fertiliser applied without using calibrated measures.

f) Applying many fertilisers at the same time to catch up with the manuring rounds. This can cause toxicity, imbalance and/or immobilisation of some nutrients, e.g. N and B.

g) Applying fertiliser when the field is full of weeds.

This list is by no means exhaustive. There is just no substitute for good and meticulous supervision of field work in the estate.

Feedback is one of the keys to successful implementation of the fertiliser recommendations and it should be part and parcel of the company's culture. This is because the responsibility of fertiliser management does not lie with the agronomist alone but ultimately with all concerned (Goh *et al*., 1999). Some of the essential feedbacks provided by the latter authors are reproduced below:

a) Wash-out after fertiliser application, which can happen in tropical countries. Additional fertiliser may be necessary.

b) Delay in fertiliser delivery of more than 2 months. Readjustment of fertiliser schedule and rates should be done.

c) Non-availability of fertiliser in the market or a substantial change in fertiliser price. Another source of fertiliser, fertiliser rate and method of application may be advised.

d) Areas with nutrient deficiency symptoms or unusual appearances of the palms. Corrective manurings or other appropiate measures such as drainage may be recommended.

e) Changes to field practices, planting dates and replanting dates. Modification to the fertiliser recommendations is usually necessary.

f) Regular reporting on palm growth and yields in problem areas. Specific corrective measures may be needed to alleviate or overcome the most limiting factor first.

SOME CURRENT CHALLENGES AND FUTURE TREND

The fertilizer management system described thus far can be regarded as traditional method commonly adopted in the oil palm plantations. It has served the industry well as evidenced by the high FFB yields, respectable returns to manuring and sustainability. But, the industry now faces many new challenges and some of them are briefly discussed below.

Labour requirements

The current plantation management system is labour intensive and many of them are deployed in manuring work. Switching to mechanical spreading of fertilizers will immediately result in tremendous saving in labour requirements but the following principal points should be noted (Chew *et al.*, 1994a):

a) Application efficiency increases when roots system of oil palms are adequately developed and spread out
b) Avoid application over eroded and compacted areas traversed by in-field vehicles which suffer severe run-off
c) Limited to areas of suitable terrain and soil types which can take vehicle load

Apart from the above points to consider, there is usually a lack of control in actual fertilizer application rate with mechanical spreader since the speed of tractor is variable and the actual traverse path of the tractor is determined by the driver. Both difficulties can probably be overcome with electronic controller and GPS.

Other responses to the high labour requirements for manuring are to reduce the frequency of application to once a year e.g. the use of FELDA or AA+ Mulch^{TM} for mature palms (Figure 11), effective sources of fertilizers, improving nutrient holding capacity of the soils and better nutrient uptake by roots. Recent results showed that applying fertilizers under the FELDA Mulch resulted in better leaf and rachis P and K concentrations of oil palms compared with broadcasting in a high rainfall region in Sarawak (Figure 12). This system reduces surface run-off and erosion of applied nutrients and avoids excessive concentration of applied nutrients at a spot. Therefore, it allows the application of fertilizers during wet weather. This method also provides better flexibility in the manuring programme and utilization of labour. However, the long-term economic returns from this system are still being evaluated.

Fertilizer prices

The volatile fertilizer prices in the past two years have been described as a “perfect storm” in IFDC report, Volume 33(4), December 2008. According to the report, numerous factors converged simultaneous to cause fertilizer prices to soar and then suddenly collapse. The latter was attributed to “demand destruction” when farmers were unable or unwilling to pay two to three times the prices of early 2007. The report further stated that the situation worsened with the collapse of the global credit market, a trade recession and slowdown in world economic growth. This depressing scenario of the fertilizer market for at least the next two years is nothing new as it has happened on a number of occasions in the past although the factors causing them might vary.

The first reaction of most farmers and planters to high fertilizer prices is generally to withdraw fertilizer inputs for better cash flow. However, as advised by Dr. Ng Siew Kee in the 1970s, we should look inwards first and examine various scopes to improve fertilizer use efficiency for greater economy in fertilizer usage. This would include adapting the various methods to fully utilize the by-products in the mill on a large scale in a practical manner as another source of soil amendments and fertilizers and not fertilizer substitutes or waste products. Thus, their agronomic and economic values must be painstakingly computed as shown in Goh *et al*. (1999). Any potential wastage in the fertilizer management system such as luxurious fertilizer regimes for the sites, poor fertilizer quality and incorrect timing of fertilizer application must be strictly attended to immediately.

The next step is to be fully aware of the factors affecting the economics of fertilizer usage as provided by Hew *et al*. (1973) and Lo and Goh (1977). Some of the major factors in the computation are the base yield, fertilizer response, discount factor, prices of palm oil and fertilizers, and agricultural risk. These factors are site dependent i.e. soils, palm age, climate and their interaction with nutrients and thus, it should be the agronomist who determines the quantum and where fertilizer should be reduced to meet the company's cash flow and anticipated profit. Ng and Goh (2003) also showed that the type of agricultural risk to be taken depends on the economic situation and cash flow of the company. Under tight cash flow or low profitability, risk preference approach is probably the best option.

In determining the fertilizer response curve, the agronomist should calculate the impact of both fertilizer withdrawal and subsequent re-application of fertilizer. An example is illustrated in the self-explanatory Figure 13 where seasonal trend has been removed. The main features to note in this graph are:

a) The decline in yield depends on palm nutritional status, soil fertility and time
b) There is a time lapse of about a year before a linear decline in yield is observed
c) The minimum yield depends on soil fertility and palm age

d) The recovery rate depends on palm nutritional status

e) When the palm is severely malnourished, its maximum yield is about 10% below its potential even after full recovery (Warriar and Piggott, 1973; Caliman *et al.*, 1994). The reason for this is still uncertain.

Reducing fertilizers or totally withdrawing them for economic reasons should always be a last resort because some yield loss will ultimately happen and the economic optimum is usually not achieved. However, it will relieve the cash flow problem of the company because fertilizer cost is the largest operational cost in managing an oil palm plantation. Thus, if fertilizer withdrawal is absolutely necessary, the following strategy might be followed but it certainly require a competent agronomist to implement it correctly:

a) Select the nutrient with the least impact on FFB yield (revenue depends on prices and thus difficult to target)
b) Any cheaper sources?
c) Select soil types/fertility with lowest FFB yield response to the nutrient
d) Select the climatic zone with least impact on FFB yield
e) Select palm age category with least impact on FFB yield
f) Go to step (a) until objective is achieved

This strategy will choose the category of palms for fertilizer withdrawal and the nutrients and quantity to be withdrawn that will result in the least impact on FFB yield allowing quicker recovery when the economic situation improves. It is also site-specific. Thus, it is superior to the usual strategy of many companies to cut fertilizers by a certain margin across the board, which may lead to drastic yield decline in areas with good fertilizer responses.

Sources of fertilizers

In 2007, urea accounted for more than 50 % of the world N production (excluding ammonia). This is also true in Malaysia where urea and urea-based fertilizers will take the lion share of the N market although in the oil palm industry, the converse may be true. The latter was due to the unpredictable N volatilization losses on inland soils which deter most agronomists from recommending it widely. If the N volatilization losses can be controlled to a predictable, narrow range for each environment, then it is possible to use urea as a main source of N for oil palm on inland soils whenever it is cost effective.

Currently, many methods are available to reduce N volatilization losses from urea such as urease inhibitors, S-coating (perhaps using 10% S only since Malaysian soils are generally acidic), humic acid, K and B. Also, slow release fertilizers and bio-fertilizers which are urea based are being marketed in Malaysia. We should conduct proper, well replicated trials to evaluate their effectiveness for oil palm on inland soils. Another way to stop or minimize N volatilization from urea is to apply it under AA+ Mulch^{TM} or FELDA Mulch.

There is also a growing interest in bio-fertilizers because of the premise that the soils under oil palm are relatively sterile due to long-term fertilizer usage, and the effective microorganisms (EM) in bio-fertilizers can rejuvenate the soils leading to improve soil fertility and subsequent better productivity. Microbes are the unseen majority in soils but despite their abundance, the impact of soil microbes on ecosystem processes is still poorly understood (van der Heijden *et al.*, 2008). The latter workers, in their extensive review, concluded that soil microbes must be considered as important drivers of plant diversity and productivity in terrestrial ecosystems. Despite this enthusiasm, there has been no conclusive evidence that introduced EM improve crop productivity in the fields. Similarly, Blal (1989) working on the effectiveness of vesicular-arbuscular endomycorrhizas on oil palm showed that it was only effective on sterile soils. Nevertheless, this new area of research should be explored albeit at a lower level to provide data on the best route to take.

Fertilizer quality

Fertilizer quality has always been a concern to the industry. Although we have SIRIM standards, they were drawn up at a time when fertilizer prices were relatively low. With the current high fertilizer prices and the improvement in laboratory techniques and fertilizer manufacturing technology, it is perhaps logical or even warranted to call for a review of the standards particularly those related to compound fertilizers and fertilizer mixture. Also, newer experimental data are now available to assess the effectiveness of various fertilizers such as rock phosphate (Chan and Goh, 1997a, Zin *et al.*, 2001) which should be incorporated into the standards.

RSPO

The creation of RSPO has added another dimension to the many aspects of an agronomist's roles because fertilizer management is part of the Principles and Criteria of sustainable palm oil under Principle 4.2. This Principle states that soil fertility should be maintained or improved to a level that ensures optimal and sustained yield by monitoring the trend of soil organic matter and net fertilizer inputs. As expounded earlier, this has always been a feature in the conventional fertilizer management system of oil palm.

Ng *et al*. (2004) showed that soil organic C decreased with time in the oil palm plantation during the period when the oil palm biomass was allowed to be burnt or partially burnt at replanting. However, large increases in soil organic C occurred with the current zero burnt replanting technique in the first few years. This positive change has not been traced over the life cycle of oil palm and moreover, there is currently no conclusive evidence to show that the improved soil organic C will lead to better or sustained productivity/yield of oil palm to the best of our knowledge. This provides a golden opportunity for researchers to undertake the study in order to understand the mechanism and impact of this important subject matter.

Chew *et al*. (1994a), Kee *et al*. (1995) and Ng *et al*. (2004) demonstrated that soil pH will decline at localised area in the oil palm agro-ecosystem such as the palm circle due to the use of acidifying N fertilizer. However, it does not appear to affect the productivity of oil palm. There is also a strong build-up of soil P and K especially in the palm circle in order to maintain adequate solution P and K for optimal uptake of these nutrients by the palms. We need to develop some methods to improve the uptake of these nutrients in the palm circles by the palms perhaps by increasing soil organic matter and/or soil pH or through soil microbes.

Chew *et al.* (1994a) in their review clearly showed that leaching losses of nutrients under oil palm were relatively low. This was supported by Foong (1993), Omoti *et al.* (1983), Schroth *et al.* (2000) and recent unpublished work at AAR where the latter showed non-significant difference in solution nitrate concentrations between the optimal N rate and without N input at 120 cm depth after 18 years of differential fertilizer treatments (Figure 14).

Chew *et al.* (1994a) and Kee and Chew (1996) also showed that the off-site effect of applied nutrients, which are mainly in the forms of run-off and erosion, were generally low at less than 15% if they were applied during suitable months for fertilizer application. The major concern here is the lack of data to assess the impact of these processes in hilly areas on the environment and fertilizer use efficiency. Nevertheless, Chew *et al.* (1994a) concluded that the major risks to the environment arise from the following:

a) At times of clearing for oil palm planting with the large release of soluble nutrients especially K from old stand of oil palm

b) Over-application of fertilizer to young palms before full development of the root system or full growth when leaching losses are highest. Split fertilizer applications are very important at this stage to improve nutrient uptake efficiency.

These two aspects of oil palm cultivation are currently subjects of active research in Malaysia.

Of interest to many researchers now is the maintenance or improvement of soil quality. In fact, in highly weathered and degraded soils of the tropics, the latter is more important to sustain high yield and profitability. However, the definition of soil quality is still subject to much debate. Nevertheless, RSPO indirectly stated that soil quality includes structure, organic matter content, nutrient status and microbiological health of the soil. While the definition of soil quality may not be the most important to our industry, we should still establish quickly some practical agro-biological indicators of the soils that have significance on the fertilizer management and sustained productivity.

Climate change and variability

Climate change and its variability have existed since time immemorial. A large proportion of these changes is natural and involves geophysical processes. However, the main concern now is the rapid rate of climate change globally that is detected recently and generally attributed to anthropogenic causes. The evidences for the latter thus far especially in the long-term have been scientifically weak. In fertilizer management of oil palm, our main concerns are the impact of fertilizer use on

a) greenhouse gas (GHG) emission
b) soil C build-up
c) energy use

In GHG emission, it is probably only relevant in “wet” soils where the risk of anaerobic conditions is higher with consequent methane and nitrous oxide emissions. Melling *et al.* (2006) showed that the application of urea to oil palm on deep tropical peat only resulted in a short-term emission of small amount of methane in the month of application (Figure 15). The effect disappeared two months after urea application. This short term effect was ascribed to reduced oxidation of methane due to its inhibition by NH_4^+ ion which was produced when urea hydrolysed. Urea application to deep tropical peat under oil palm has no significant effect on nitrous oxide emission (Melling *et al.*, 2007). Although these results showed that urea has little or no role on GHG emission from tropical peat under oil palm, further work is necessary for a firm conclusion to be made.

Fertilization has been shown to enhance the productivity of oil palm with consequent better rooting system of more than 12 t dry matter per ha. However, the sequestration of this organic matter to soil organic C in different environments is still uncertain. There is also a lack of data on C sequestration from the various sources of organic matter produced by the oil palm e.g. pruned fronds, EFB, POME and decanter cake, and the leguminous cover crops. This information has a large bearing on the C cycle of oil palm and its impact on climate change.

The energy balance of oil palm has been estimated by a few workers such as Wood and Corley (1993), Reijnders and Huijbregts (2008) and Wicke *et al*. (2008). However, they generally did not include the latest technology of fertilizer production which is more energy efficient (de Vries, 2008), the increasing use of locally manufactured urea based fertilizer and recycling of oil palm biomass residues and mill by-products and thus, probably grossly over-estimated the energy use in oil palm plantation. It is critical that a new life cycle analysis (LCA) of the energy balance of oil palm be made in view of the pressing need to correctly inform our buyers, consumers and NGOs with scientifically based data.

Competent agronomists

The current and future crop of agronomists has a formidable task not only to improve fertilizer use efficiency and palm oil yield but also meet the many challenges listed above and future work below. Thus, they must have the leadership and creativity to meet these challenges and the courage and commitment to pursue and persevere towards their convictions and maintain the highest standards possible. The ability to adapt to change and avoid self ego is essential if we are to maintain our edge over the competing vegetable oil crops in the long run. Also, the agronomists are now regularly requested to evaluate untested products for the plantations. They must maintain their integrity and based their decisions on scientific ground and guiding principles of soil and plant nutrition, and do not allow friendship and emotion to cloud their judgement. The other roles of agronomists were well described by Chan and Goh (1997b) and Chew and Goh (2003). The cooperation between agronomists from different organisations should continue to be fostered and joint research work initiated to solve problems of common interest. With the rapid expansion of oil palm worldwide, the number of agronomists required has also increased correspondingly and the lack of competent agronomists is becoming apparent. The industry will do well to provide the necessary atmosphere, coercion, training, facility and remuneration to attract the best and ensure that this unenviable task is under good hands.

FUTURE WORK AND CONCLUSION

Fertilizer management plays a pivotal role in the productivity and profitability of oil palm. At times of high fertilizer costs and/or low palm oil prices, questions about how fertilizer rates can be trimmed and risks managed will be frequently asked. Unfortunately, there are no general quick fixes and individuals have to assess for themselves the risks they are willing to take (Murrell, 2009) and falling back to the guiding principles of fertilizer management of oil palm. In fact, in this paper, we have outlined the fundamental of oil palm nutrition and the principles behind recommended fertilizer management, a good knowledge of them is highly essential to implement the strategy to tackle the uncertainties and economics difficulty with informed and evidence-based decisions rather than personal perception and preference.

The future work in oil palm agronomy has been well discussed by Soh *et al*. (2006), Kee and Goh (2006), Goh (2005), Chew and Goh (2003), Kee *et al*. (2003) and Chew *et al*. (1997) just to name a few from AAR only amongst the many from other organisations in the oil palm industry over the years. It is neither our duty nor the place here to summarize these papers but to complement them.

The principles and philosophy of nutrient budget have served us well as evidenced by the high productivity of oil palm despite being largely grown on weathered, degraded soils in the tropics. Currently, the oil palm has probably the best nutrient use efficiency per tonne of vegetable oil. While the K budget can account for the optimal K rates in fertilizer response experiments, the N budget cannot explain over 30% of the N balance (Table 14) in the same set of experiments. This will require the more difficult research work on nutrient cycling and dynamics, which should yield results for further improvement of fertilizer use efficiency of oil palm. This work should include other minor nutrients and elements known to affect crop performances.

The roles of biotic factors on palm nutrition are expected to become more prominent as we breed for truer inbred hybrids with more uniform (identical) genetic make-up on a commercial scale. Similarly, the greater use of clones and re-clones will necessitate the study of their specific or differential nutrient requirements. For example, in Clone 1, there was hardly any response to K fertilizer inputs after years of experimentation compared with Clone 2 and DxP materials (Figure 16). Similar results have been reported by Jacquemard *et al*. (2002) and Donough *et al*. (1996). Another black box in oil palm nutrition is the roles of soil microbes and biodiversity. This needs urgent studies if we are to exploit this largely unknown soil resource.

The lack of study on physiological plant nutrition in the oil palm industry is still glaring. This deficiency must be addressed quickly to understand the various phenomena seen in the fields such as pre-mature frond desiccation, relationship between pest and diseases and palm nutrition, the root system and its mechanism for nutrient uptake, and the roles of plant nutrition in climate change amongst others; and develop new direction for studying plant nutrition and better, practical fertilizer use technology.

In the seventies and early eighties, there was much co-operation among the research organisations in Malaysia for joint research on common problems and meta-analysis of experimental data. For example, the combined analysis of fertilizer response trials from the industry by Dr. Foster and co-workers has resulted in a fertilizer recommendation system for oil palm and a set of indicators of palm health (Goh, 2005). However, newer agronomic data are now available and these experiments are conducted with later generation of planting materials and current recommended management practices on more diverse soil types and environments, which are probably more relevant to the industry today. Thus, it appears logical to conduct another meta-analysis of these newer data.

The palm oil mills should be regarded as large stores or reservoirs of nutrients/fertilizers and carbon/organic matter. The current methods to utilize these resources are still tedious, laborious, cumbersome and limited to specific areas. Furthermore, the expensive soluble nutrients such as K are probably not fully recovered. Theoretically, if all the nutrients can be recovered, the oil palm industry needs very little fertilizers because our main produce, palm oil, does not contain much nutrients. While we are not suggesting turning the palm oil mill into fertilizer factory, scrutinizing for new technology to recover these nutrients and carbon and making them user friendly e.g. granulation or liquid fertilizers are urgently needed. In fact, a growing number of agronomists worldwide has the opinion that producing higher yields requires not only advanced genetics but good agronomic management which includes good plant nutrition utilizing both organic and inorganic nutrient sources (Roberts, 2009). Apart from the above impact, it will have huge implications on carbon credit, carbon balance, energy balance, sustainability and a host of other initiatives related to global palm oil trade.

Research work on precision agriculture in oil palm has commenced in the 1990s and its potential applications have been demonstrated (Goh *et al.*, 2000). For example, the generation and combination of yield maps of plots with and without nitrogen application in a classical fertilizer response trial (about 25 ha) using geostatistical methods showed strong spatial yield responses to nitrogen (Figure 17). They ranged from good FFB yield response of more than 50 kg/palm/yr or 6.6 t/ha/yr in the central portion of the field to poor or negative yield responses in the eastern and western parts. This information can be transformed into management zone for site-specific management (Anuar *et al.*, 2008). Further work is needed to exploit this technology for improved effectiveness and efficiency of inputs leading to better productivity and profitability.

The oil palm environments comprise numerous elements or growing conditions where their interplays have a strong impact on the yield response to fertilizer inputs. For example, Kee and Chew (1993) demonstrated that the N rate may be reduced by half under irrigated compared with non-irrigated oil palm in an area with monsoonal climate (Figure 18). This was attributed to better nutrient uptake under adequate soil water throughout the year ensuring optimal palm nutritional status at most times with consequent fuller expression of FFB yields. Similarly, FELDA Agricultural Services Sdn Bhd. (FASSB) clearly showed that the FFB yields of oil palm under irrigated condition in a dry region were consistently higher (35% or 45 t/ha over five years) than non-irrigated condition given the same fertilizer regime (Figure 19). These results indicate that we may need a series of multi-factorial trials to decipher and understand the role of each growing condition on fertilizer response and to provide the recommended set to the planters to implement for best results. In fact, it is of utmost importance that the agronomists identify these conditions and design farming system that optimises the fertilizer use efficiency.

Technology, techniques and equipment are now available and there are hardly any reasons why these studies cannot be undertaken successfully. What is needed is creativity and ingenuity to solve our problems. As published by The Sunday Star, the local newspaper on 5th April 2009, “Science triumphs common sense when it really matters”. Thus, the future of effective fertilizers, fertilizer use efficiency and fertilizer management, and the consequent productivity of oil palm reside in continuous generation of new applicable sciences, adaption of new technologies and designing new methods to implement them correctly and efficiently, and reducing the uncertainties related to fertilizer management.

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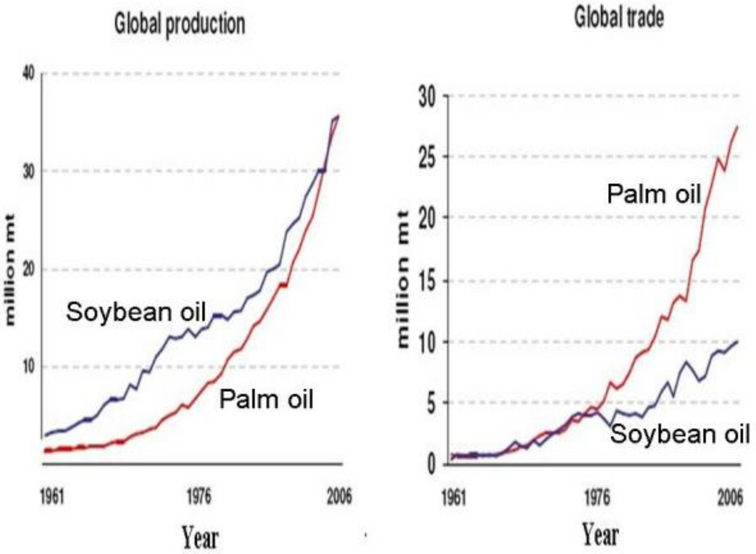
Figure 1: Global production and trade for palm oil and soybean oil



Source: Thoenes (2006)
Legend: Red line – palm oil; blue line - soybean

Figure 2: Effects of period of planting on oil palm yield trends in AAR advisory estates (from Goh *et al.*, 1994)

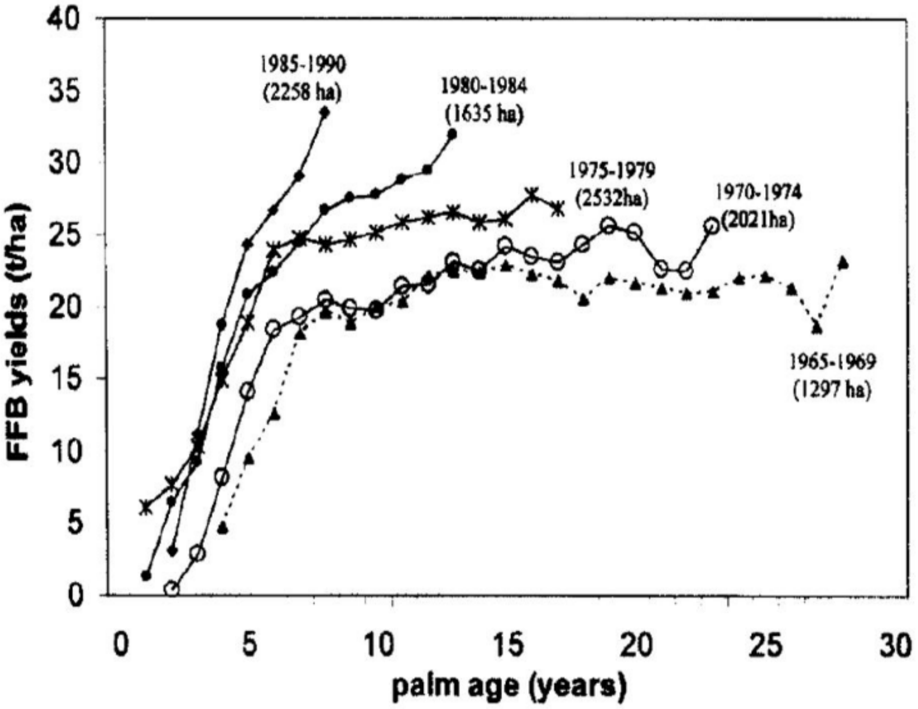


Figure 3: Vegetative growth and yield profile of well grown oil palms on inland soil in Malaysia

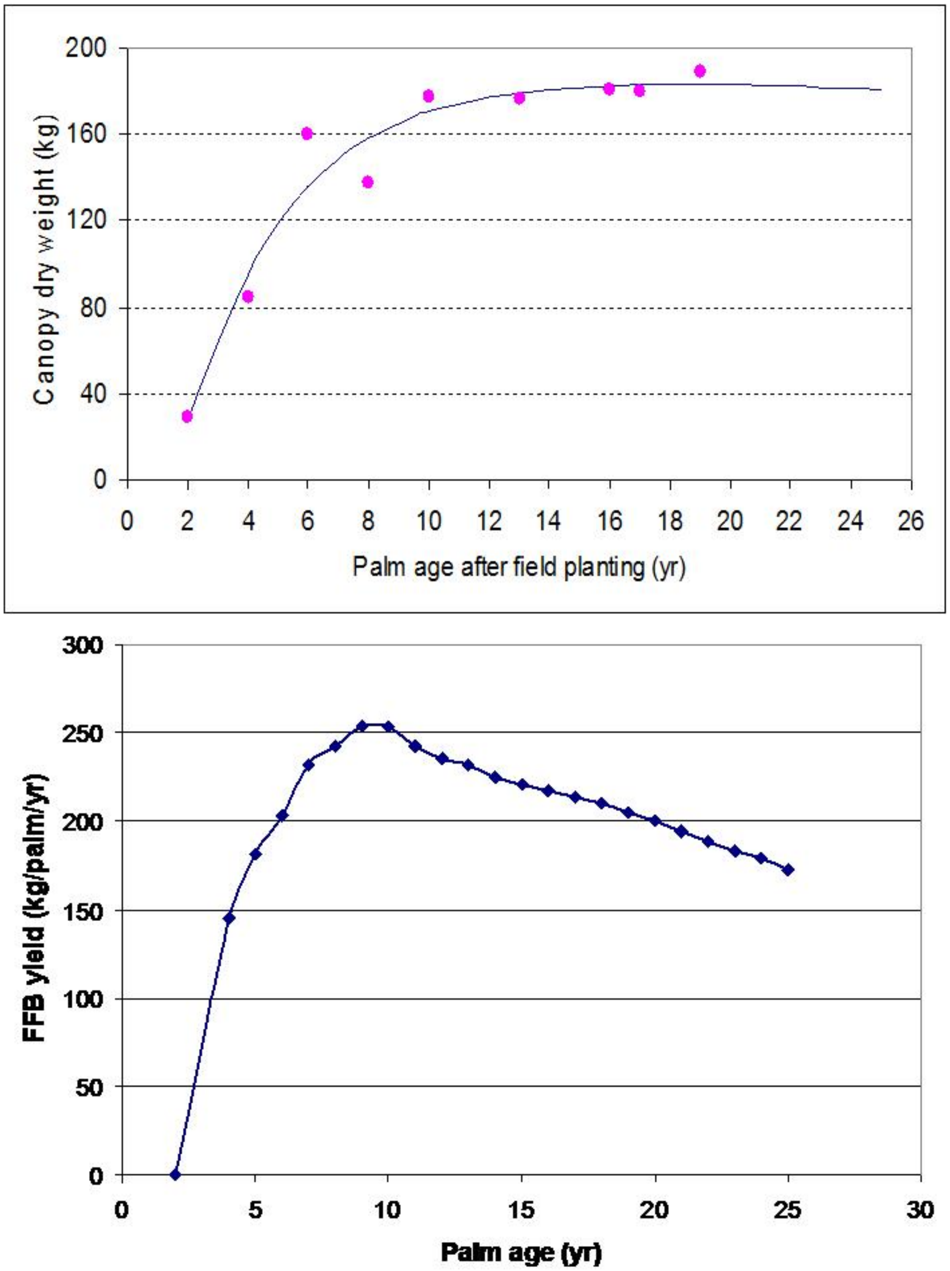


Figure 4: Effect of increasing mature areas (ha) on FFB yields of 11 large commercial plantation companies in Malaysia in 2006

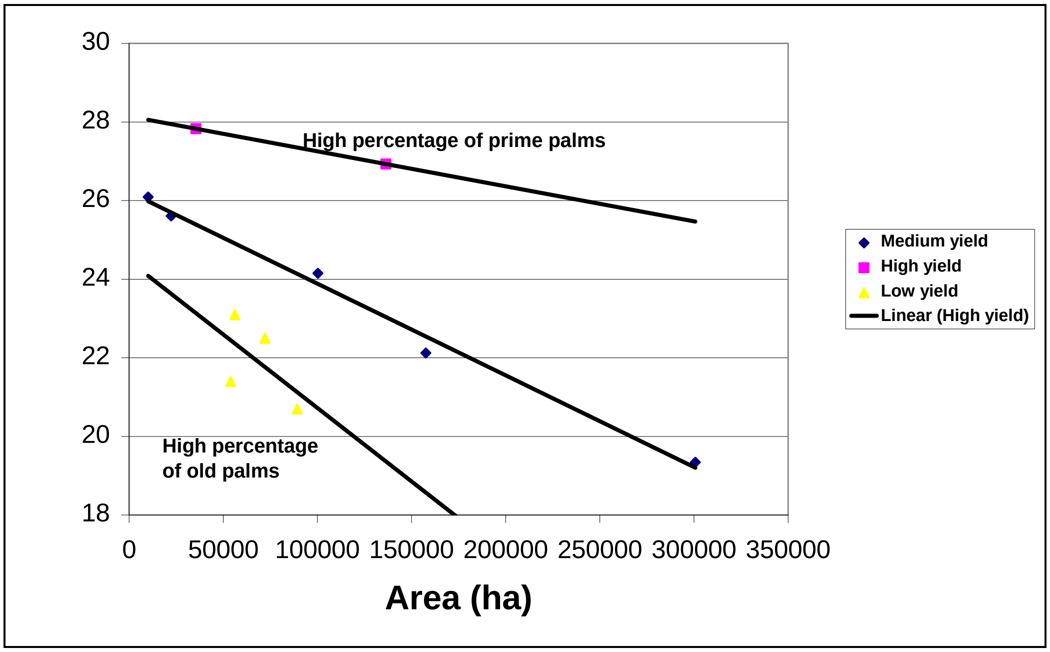


Figure 5: Long-term responses of FFB yields to K fertilizer rates in coastal soils with low bases (y-axis shows the relative yields of plots with and without K input). After Xavier *et al.* (2008)

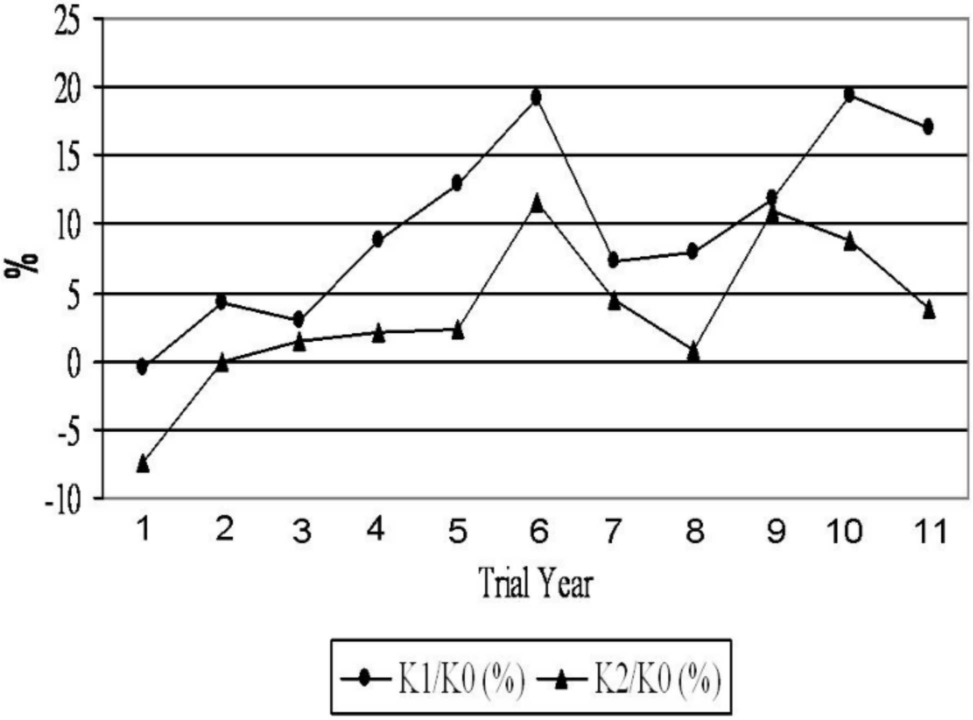
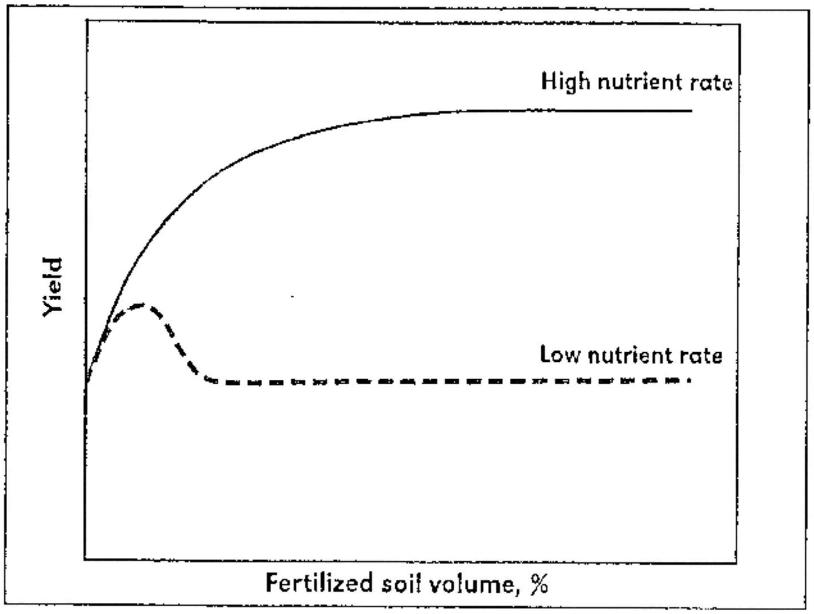


Figure 6: The needs for increasing fertilized soil volume to meet nutrient demand for yield at high and low nutrient rate



Source: Murrell and Bruulsema (2008)

Figure 7: Effect of concentrations of nutrient solution on roots and leaf of oil palm

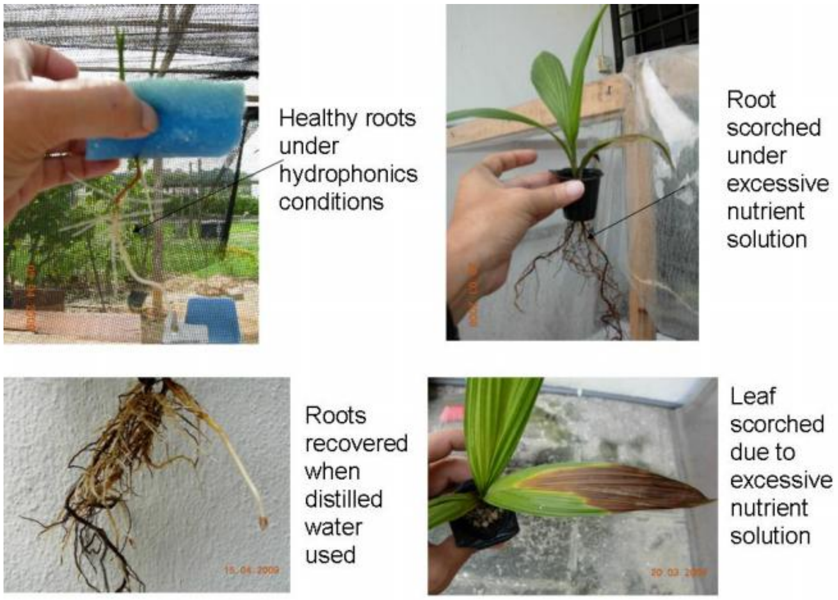
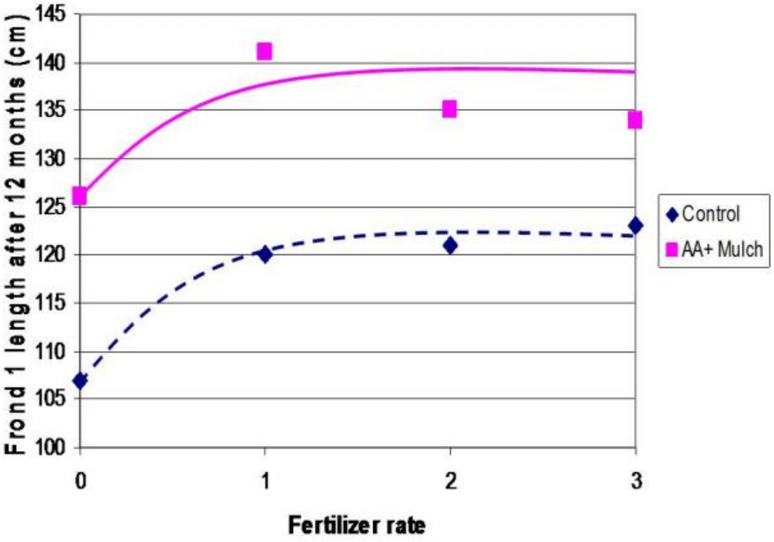


Figure 8: A composite picture showing the use of Felda mulch and AA+ plastic mulch for immature oil palms. The latter, which was a replicated trial in Bahau district (rain-shadowed region) clearly showed the superiority of AA+ plastic mulch where palms' canopy sizes were larger with good vigour compared with those without mulch.

FELDA mulch at time of planting

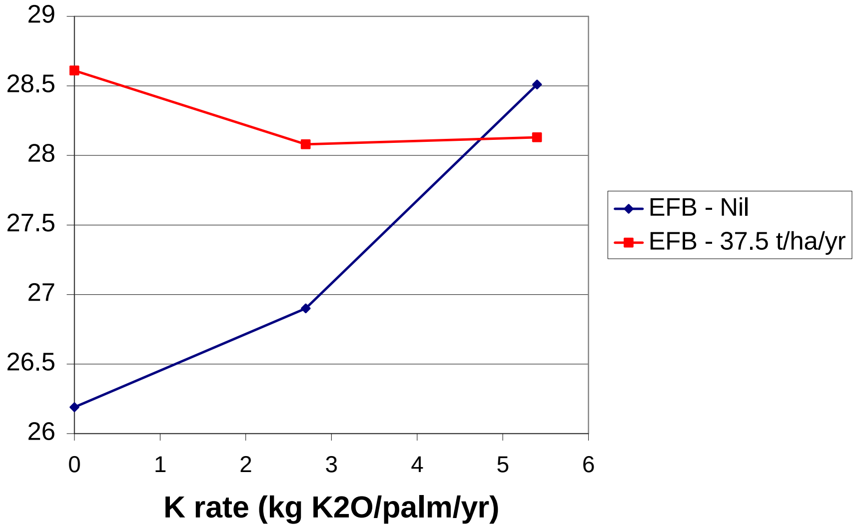
With and without AA+ plastic mulch a year after planting in a replicated trial

Figure 9: Effect of AA+ mulch on frond length of 1 year old palms on Gajah Mati series (shallow lateritic) soils in a rain-shadow plantation



Source: Ng and Goh (2008)

Figure 10: Effect of EFB on FFB yield response to K fertilizer in Durian series soil in Malaysia



Source: Recomputed from Chan *et al.* (1993)

Figure 11: Experimental testing of FELDA mulch for mature palms to reduce the frequency of fertilizer application and surface run-off losses of nutrients.

Source: Lee *et al.* (2008)

Figure 12: Effects of methods of fertilizer application using FELDA Mulch (FM) and broadcasting (FSP) on leaf and rachis nutrient concentrations of oil palms. Trial was layout in a high rainfall region in Lundu, Sarawak (FASSB, unpublished)

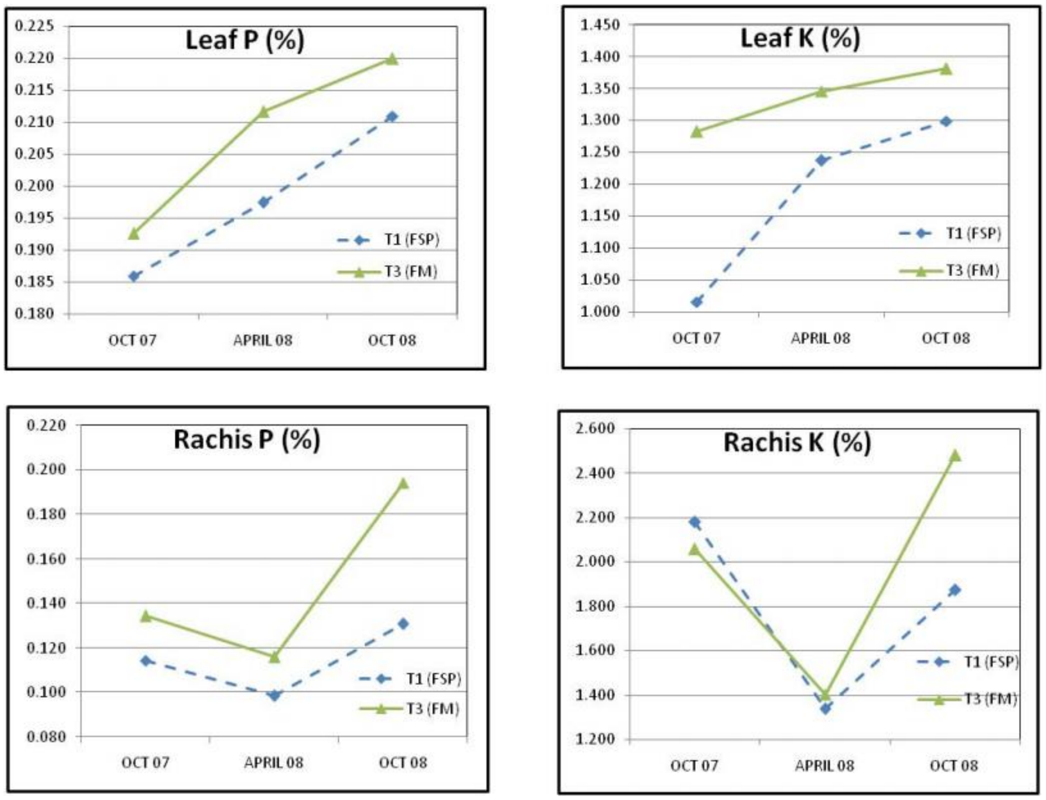


Figure 13: Predicted effects of fertilizer withdrawal and resumption on FFB yields in Malaysia using AAR's combinatorial model. Source: AAR (Unpublished)

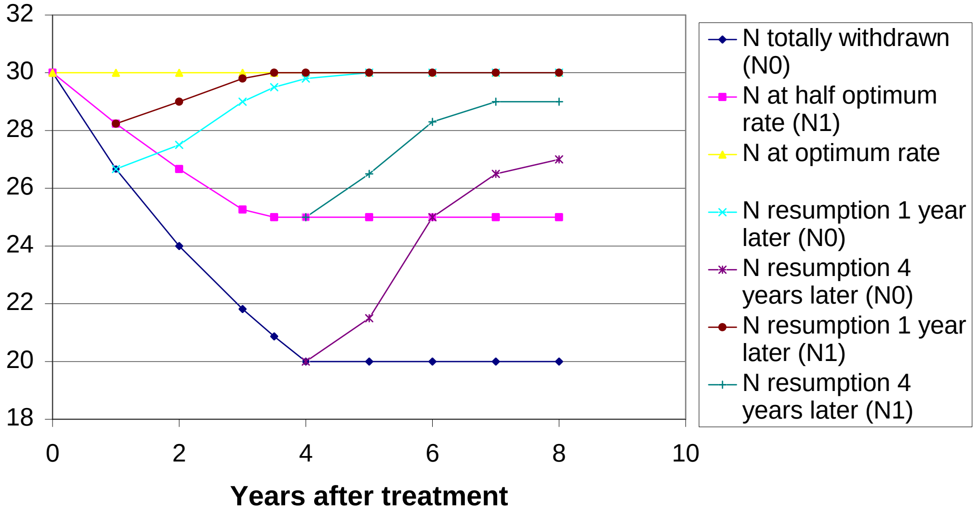


Figure 14: Leaching losses of nitrate under oil palm on an ultisol after 16 years of differential N inputs. Source: AAR (Unpublished)

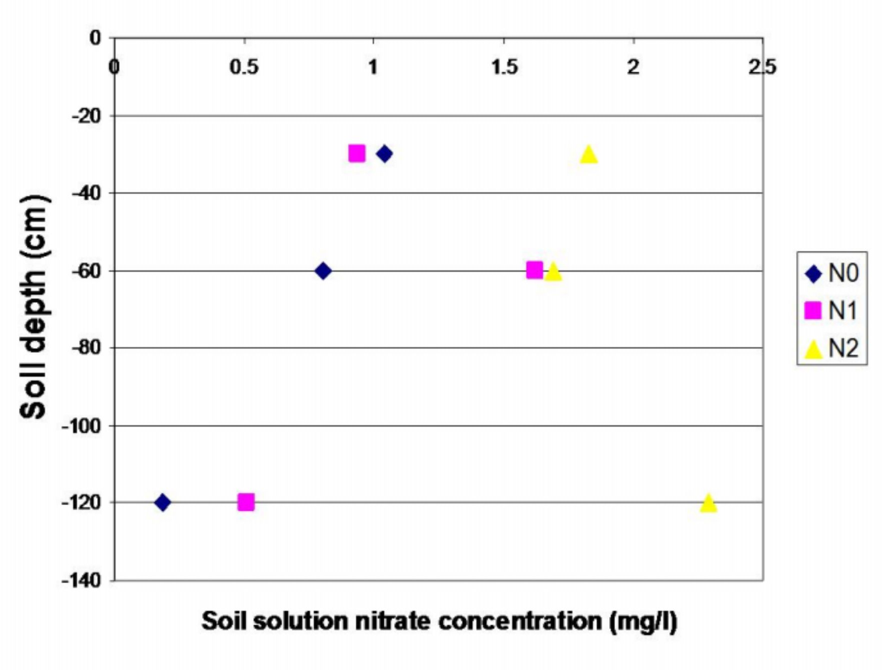
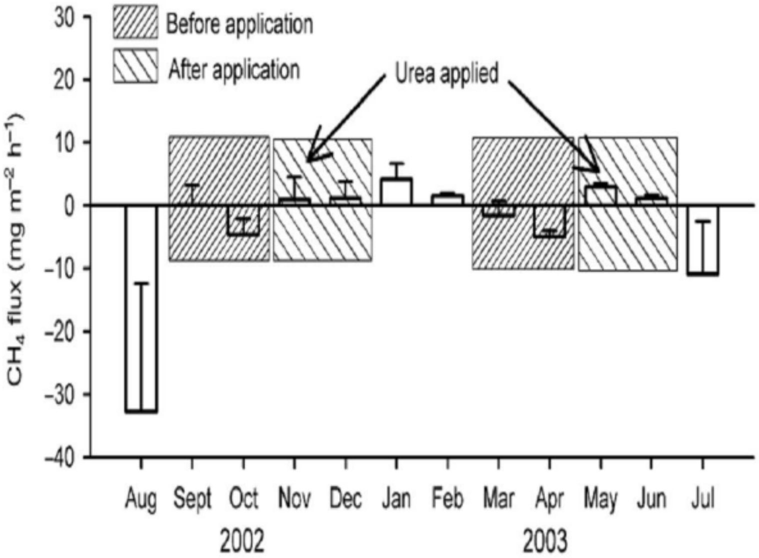


Figure 15: Monthly CH4 flux before and after urea application at the oil palm plantation. Data represent mean ± standard error (n = 3)



Source: Melling *et al.* (2006)

Figure 16: Differential FFB yield responses of oil palms propagated by tissue culture (clonal) and seeds (DxP) to K fertilizer in Kumansi Family soil in Sabah, Malaysia. Average yields between 2003 and 2008 were shown in the graph. Source: AAR (Unpublished)

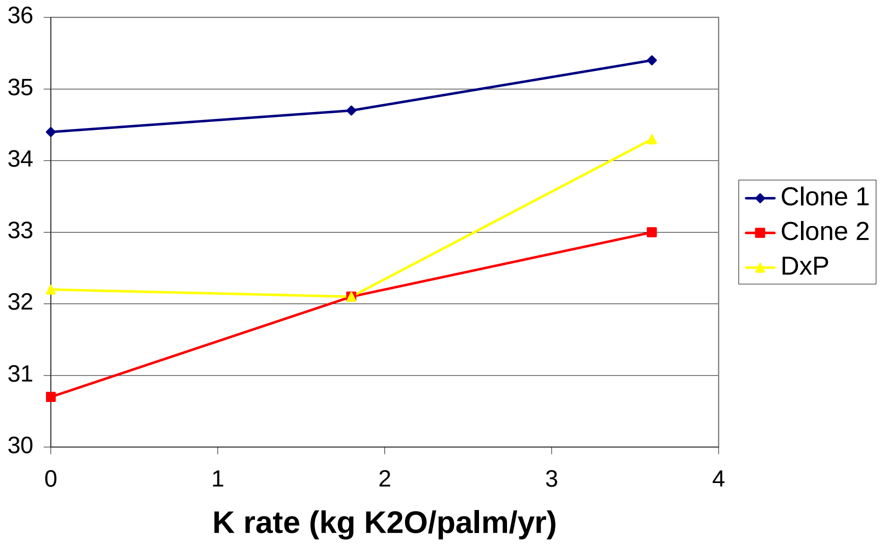
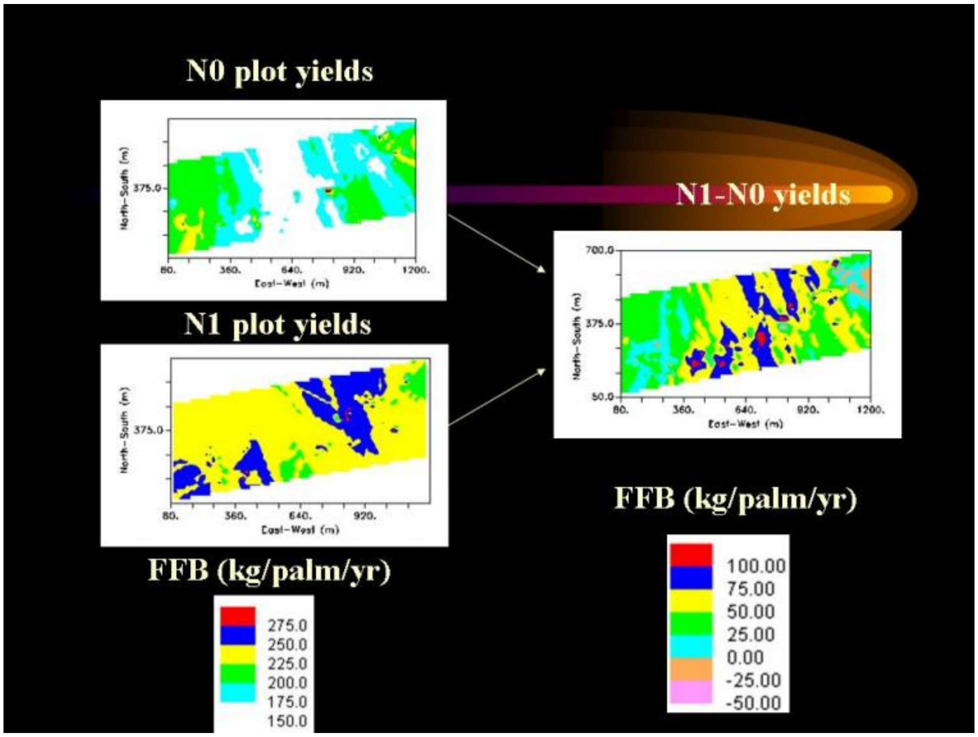
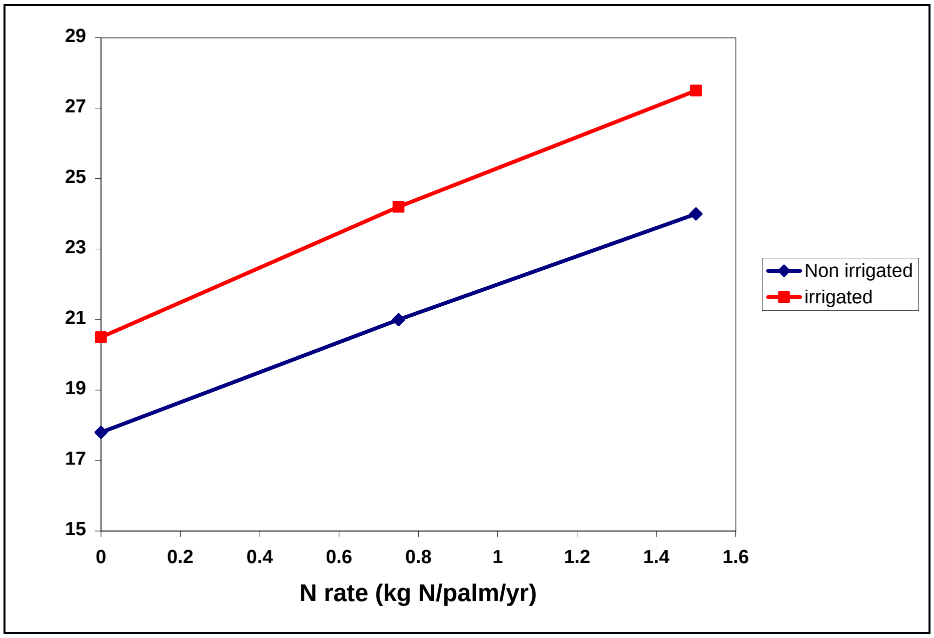


Figure 17: Spatial FFB yield response of oil palms on Kumansi Family soil to N fertilizers



Source: Goh *et al*. (2000)

Figure 18: Effect of irrigation on N response of oil palm in a wet monsoonal climate in Malaysia



Source: Kee and Chew (1993)

Figure 19: Effect of fertilizer (N1P1K1) on oil palm yields in a dry region under irrigated and non-irrigated (FASSB, unpublished)

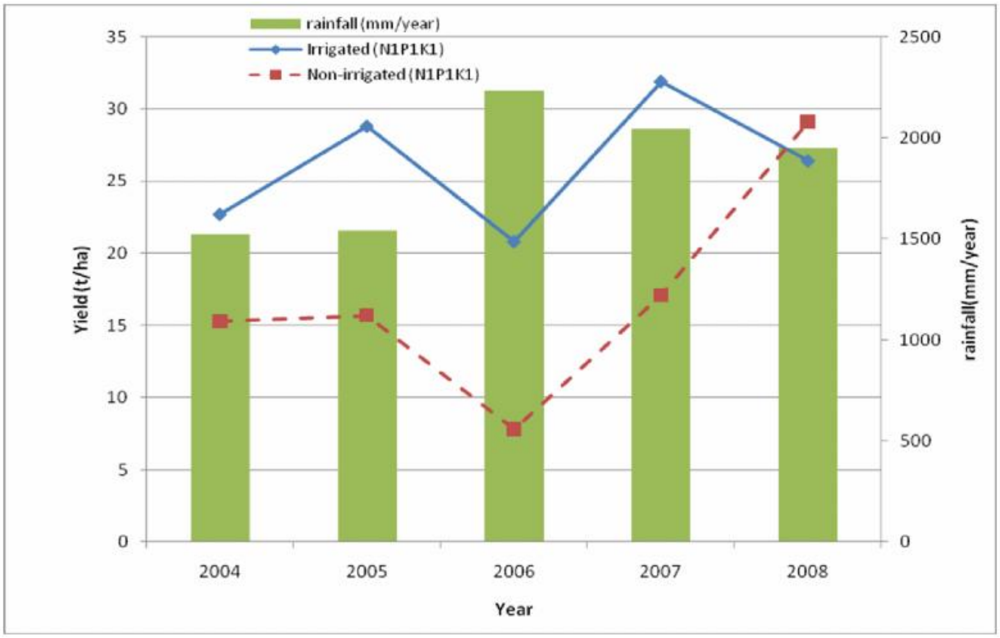


Table 1: Area and additional area of oil palm and soybean required to meet demand for vegetable oil in 2050

Category	Rate of consumption (kg/person)	Oil required (million tons)	Current area (million ha)		Additional area (million ha)		Total area (million ha)	
			Oil palm	Soybean	Oil palm	Soybean	Oil palm	Soybean
Low	20	117	11	92	18	216	29	308
Medium	25	156	11	92	28	319	39	411
High	37	256	11	92	53	582	64	674

Note: Palm oil and soybean oil yields were assumed to be at current levels of 4 and 0.38 t/ha/yr

Table 2: Current yield gaps (t/ha/yr palm oil) in Malaysia

Scale	References	Yield (t palm oil/ha/yr)
Theoretical maximum yield	Corley (1985)	17
Small scale breeding trials	Mohd Din *et al*. (2005)	12
Best trial yields	Jalani *et al*. (2003)	8.6 – 11.5
Best field yields	Goh et al. (2002)	4.7 – 6.8
National yields	Tinker (2000)	3.0 – 4.4

Table 3: Fresh fruit bunch yields (t/ha/yr) in maximum yielding and control (without fertilizer) plots from oil palm fertilizer trials

Trial period	Site	Soils	Maximum	Control
1970s – 80s	Inland	Bungor	31.8	8.6
		Rengam	27.7 – 32.5	11.2 – 18.2
		Serdang	32.3	12.0
		Durian	25.6 – 36.8	13.0 – 23.0
		Munchong	29.9 – 34.6	11.6 – 24.4
		Batu Anam	25.5 – 33.0	17.3 – 28.1
		Malacca	27.9 – 29.3	22.9 -25.9
		Kumansi	31.2	23.6
		Batang	33.8	28.9
	Coastal	Carey	27.8 – 31.9	18.5 – 25.8
		Selangor	35.1 – 36.1	30.0 – 34.0
		Sedu	31.2	22.8
		Briah	23.7 – 31.1	18.3 – 27.4
	Riverine	Akob	26.2	20
		Sogomana	29.0	24.8
		Lumisir	30.3	26.4
		Koyah	32.7	21.1
		Inanam	20.8	16.7
		Buran	33.7	29.1
1980s – 90s	Inland	Rengam	34.4 – 38.5	12.1- 23.8
		Munchong	35.2	22.8
		Batang (lat)	39.7	21.2
		Kumansi	37.9 – 45.8	18.9 – 25.7
		Sahabat	38.8	24.6
	Coastal	Carey	28.8	27.1
		Briah	30.3	25.7
	Riverine	Inanam	44.1	19.9
		Buran	41.5	25.4

Source: Kee and Goh (2006), Foong *et al.* (1996) and AAR (Unpublished)

Table 4: Maximum and average yields of oil palms in different environments in Malaysia

Environment	Maximum yield (t/ha/yr)	Average yield (t/ha/yr)
Good	35	29
Satisfactory	30	26
Fair	25	21
Poor	20	17

Note: Average yields between 4 and 25 years after planting

Table 5: Yields per hectare (ton product/ha/yr) in oilseeds and palm oil

Crop	Location	1972/73 – 79/80	1980/81 – 89/90	Change [2]	1990/91 – 99/00	Change [2]
10 Oilseeds	World	1.03	1.19	+15.5 %	1.38	+16.0 %
Soyabean	World	1.61	1.77	+9.9 %	2.11	+19.2 %
	U.S.	1.91	2.04	+6.8 %	2.48	+21.6 %
Rapeseed	World	0.86	1.22	+41.9 %	1.41	+15.6 %
	Canada	1.08	1.22	+13.0 %	1.35	+10.7 %
Palm Oil	World	2.55	3.08	+20.8 %	3.20	+3.9 %
	Malaysia	3.40	3.57	+5.0 %	3.56	-0.3 %

After Mielke (2000)

[1] Ten-year averages except 1972/3 – 79/80 (8 years)
[2] In %, from previous 10 (8) year average

Table 6: Costs of production of palm oil in producing countries in US$ per t palm oil

Country	Total Field Costs	Total Milling Costs	Total Costs US$/ t cpo	Total Costs RM/ t cpo
Indonesia	155.1	10.1	165.2	628
PNG	196.7	19,1	215.8	820
Malaysia	221.3	12.2	239.4	910
Colombia	234.5	58.3	292.8	1113

After Tek (2002)

Table 7: Increase in palm oil yield, 1951-1990, from Pamol estate, Kluang, Malaysia

Yield improvement factor	Relative increase (%)	Yield (t oil/ha)	% of total yield increment
Actual yield, Pamol, Kluang (only K applied)		1.30	
Complete fertilizer regime	+93	2.50	29.1
Deli Dura selection	+40	3.50	24.2
Introduction of Teneras	+32	4.64	27.6
Polybag nursery	+3	4.78	3.4
Drainage and water conservation	+5	5.02	5.8
Introduction of *E. kamerunicus*	+1	5.08	1.4
Increased factory efficiency	+8	5.43	8.5
Actual yield, Mamor 1989/90		5.43	

Source: Re-computed from Davidson (1993)

Table 8: Effect of NK interaction on yield and growth of oil palm on Rengam series (Typic Paleudult) soil in Malaysia.

Parameters	Nitrogen levels	Potassium levels			s.e.
		K0	K1	K2	
FFB Yield (kg palm $^{-1}$ y^{-1})	N0	71.6	65.3	66.3	4.3
	N1	68.4	95.2	95.8	
	N2	79.1	95.8	98.6	
Vegetative growth (kg dry matter palm^{-1} y^{-1})	N0	88.9	84.0	89.2	4.0
	N1	96.6	117.4	119.4	
	N2	106.4	120.0	123.0	

Source: After Chan (1982)

Table 9: Yearly variations in FFB yields (t/ha/yr) on different soil types in Malaysia.

Soil	Treatment	Year after treatment							Mean	CV
		3	4	5	6	7	8	9		(%)
Briah	Control	33	40	27	20	21	23	22	26	20.0
	Optimum	33	33	31	29	26	29	27	31	14.2
Bernam	Control	22	20	10	15	11	12	12	14	29.3
	Optimum	27	25	17	24	17	19	24	22	17.1
Sogomana	Control	31	27	23	25	27	20	32	26	15.0
	Optimum	35	36	28	31	31	32	32	32	7.5
Rengam	Control	24	22	18	22	26	22	17	21	13.5
	Optimum	26	28	28	26	34	32	23	28	12.8
Malacca	Control	11	14	12	12	16	18	13	13	18.5
	Optimum	21	23	20	24	26	37	28	25	21.2

Adapted from Tayeb *et al.* (1990) and Lim *et al.* (1982)

Table 10: Effect of various techniques to improve fertilizer use efficiency in oil palm plantations

Practice	Treatment	Yield (t/ha/yr)	% difference	Absolute difference from best treatment (%)	Standardised difference (%)	Reference
Method	Aerial	23.01	127	12	70	Lim *et al.* (1992)
	Hand	23.87	132	7	82	
	Mechanised	25.16	139	0	100	
	Nil	18.1	100	39	0	
Method	Sub-soiling	19.1	127	23	55	Manjit *et al.* (2002)
	Broadcast	22.5	150	0	100	
	Nil	15	100	50	0	
Frequency	Twice a year	18.4	136	9	81	Teoh and Chew (1985)
	Once a year	19.6	145	0	100	
	Once in 2 years	18.7	139	6	86	
	Nil	13.5	100	45	0	
Sources	Ammonium sulphate	28.19	104	3	55	Lim *et al.* (1982)
	Nitro26	28.24	104	3	58	
	Ammonium nitrate	28.77	106	1	86	
	Ammonium chloride	29.02	107	0	100	
	Nil	27.18	100	7	0	
Placement	Within palm circle	23.1	151	8	87	Chan *et al.* (1993)
	Outside palm circle	24.3	159	0	100	
	Nil	15.3	100	59	0	
Timing	February (dry)	25.38	101	11	8	Teoh and Chew (1980)
	August (normal)	28.24	112	0	100	
	Nil	25.12	100	12	0	

Note: Standardised difference (%) was probably over-estimated when absolute difference from best treatment (%) was less than 20%.

Table 11: Effect of burying the fertilizers compared with surface application on FFB yields of oil palms across various soil types

Trial	Site	Method of fertilizer application	Avg. yield per year in t/ha (%)	Soil and terrain
BS[1]	Sabah	Normal	26.0 (100)	Tanjong Lipat family on hilly terrain
		Bury (2 rds/yr)	21.5 (83)	
UD[2]	Sabah	Normal (4 rds)	25.4 (100)	Paliu family on undulating terrain
		Bury (2 rds/yr)	23.6 (93)	
FD[3]	Negeri Sembilan	Normal (4 rds/yr)	33.9 (100)	Not available but possibly on Durian series.
		Bury (1 rd/yr)	32.6 (96)	
TW[4]	Sibu	Normal	19.4 (100)	Anderson 3. Flat
		Bury	17.2 (87)	
AAA[5]	Indonesia	Normal	22.5 (100)	Alluvial. Flat
		Bury	19.1 (85)	

Source 1: Soon and Hoong (2002) 2: Kwan (2002) 3: Azmi *et al.* (2002) 4: Lim *et al.* (2003) 5: Manjit *et al* (2002)

Table 12: Effect of synthetic mulch on the growth of 12 months old palms at PPPTR research station

Treatment	Frond production		Frond dry weight (kg)		Leaf area (m^2)	
	Value	%	Value	%	Value	%
No mulch	12.96	100	9.17	100	1.06	100
FELDA Mulch 4’x4’	12.86	99	9.24	102	1.12	105
FELDA Mulch 6’x8’	14.53	112	11.22	122	1.35	127
AA+ plastic mulch 8’x8’	14.50	112	11.61	127	1.22	115
LSD 5%	1.51		2.07		0.36	
Significant difference	*		*		n.s.	

Source: Lee *et al.* (2008)

Note: AA+ plastic mulch was cut to sub-optimal size for comparison with Felda mulch. The optimum size of AA+ plastic mulch is

Table 13: Effect of uneven fertilizer applications on the early yields (8 months of crop) of six years old oil palm in Kalimantan, Indonesia. Source: Goh *et al*. (1999)

Parameters	Block 1	Block 2	Block 3	Mean
Bunch production (per ha)	1518	2305	2843	2222
C.V. %	16.2	10.0	3.7	-
FFB (per ha)	4.03	8.69	13.20	8.64
C.V.	23.9	27.2	14.8	-
Estimated FFB (per ha per yr)	9.9	18.5	25.5	17.97

Note: Each block consisted of 84 palms (7 replicates x 12 palms/replicate).
Block 1 – palms furthest away from roadside (Row 11 to Row 15)
Block 2 – palms second furthest away from roadside (Row 6 to Row 10)
Block 3 – palms nearest to roadside (Row 1 to Row 5)

Table 14: Nutrient balance computations for commercial areas. Source: Chew *et al.* (1994b)

Commercial areas	Soil series	% N balance	% K balance
1	Tavy	-32.5	+1.0
2	Munchong	-38.6	-6.7
3	Tavy/Gajah Mati	-27.8	+8.3
4	Prang/Local Alluvium	-39.1	-0.3
5	Munchong/Tavy	-36.3	-1.9
6	Bungor/Batu Lapan	-30.7	+1.0
7	Munchong/Rasau	-35.8	+4.5
8	Munchong/Holyrood	-37.1	-0.9
9	Munchong	-32.7	+14.2