FERTILISER MANAGEMENT IN OIL PALM – AGRONOMIC PRINCIPLES AND FIELD PRACTICES

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1.0 INTRODUCTION

1.1) Many papers have been written to highlight the importance of fertilisers for oil palm. The main premise is that healthy palms will produce optimum FFB (fresh fruit bunch) yield, which is the primary commodity of most plantations.

1.2) Oil palm is unrivalled in its ability to convert solar energy into dry matter and vegetable (palm) oil. However, this process requires a large amount of nutrients which must be supplied by the soil or fertilisers.

1.3) Unfortunately, most soils grown with oil palms have low soil fertility and therefore, mineral fertilisers are usually necessary to achieve and sustain good palm nutritional status and large yields.

1.4) In fact, fertilisers alone constitute about 24% of the total production cost of oil palm in Malaysia. The present economic slowdown has caused the Malaysian Ringgit to depreciate against the US dollar with the consequent rise in most fertiliser prices. This has increased the production cost of oil palm by as much as 13 %.

1.5) One of the best means to reduce production cost is to sustain maximum yield at any one site. The maximum yield is usually close to the optimum yield because of the high indirect costs in oil palm management. However, the optimum yield is subject to the vagaries of commodity prices and therefore, difficult to predict, let alone sustain. Hence, we advocate the approach to maximise and maintain the highest yield possible at any one site, which is also known as site yield potential.

1.6) The above is one of the central tenets of plantation management because it enables the highest revenue to be attained at the lowest possible cost for an assured best profit. This will help to enhance the attractiveness of the oil palm industry.

1.7) In fact, the ability of the oil palm industry to compete with others is highly essential if we are to attract reliable and skilled workers and reduce the high turn-over of work force. This is vital towards the long-term sustainability of oil palm plantations.

1.8) The above points show that the benefits of sound fertiliser management for oil palm go beyond preventing nutrient deficiency and maintaining healthy palms, which have long been recognised by the industry. Therefore, it is not surprising that the Malaysian oil palm industry has invested millions of dollars in research and development on fertiliser use since the 1920's when oil palm was first commercially grown.

1.9) These lecture notes discuss the main issues of fertiliser management in oil palm in the face of the changing scenarios in plantation management. It covers the following:

a) Agronomic principles in fertiliser management

b) Field practices for sound fertiliser management

c) Criteria and indicators of palm health and good fertiliser management

2.0 Agronomic principles in fertiliser management

2.1) Objectives of fertiliser management

i) The objectives of fertiliser management in oil palm used to be straightforward as follows:

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 fertilisers in the prescribed manner over the areas of the estate that are likely to result in the most efficient uptake of nutrients.

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

ii) However, the following conditions make achieving the objectives a challenge nowadays:

a) Shortage of reliable and skilled workers, and high turn-over in work force.

b) Environmental concerns which are related to over-fertilisation, land degradation, and pollution from heavy metals e.g. cobalt and eutrophication by P.

c) Expansion of oil palm into areas with little information on the soil properties, climate etc which are necessary for good fertiliser management e.g. the cultivation of oil palms on ultrabasic soils.

d) Managing larger manuring blocks which can result in over generalisation. In fact, this approach goes against the current trend of site-specific fertiliser management and precision agriculture.

e) Rising fertiliser prices which increase production costs.

f) Planting oil palm in countries where lack of clear law and order can be a yield-limiting factor e.g. Indonesia and southern Phillipines.

iii) Therefore, the agronomic principles of an effective fertiliser management should take all the above into account and balance the above needs and objectives with the resources in the estates. The key steps are:

a) Determine the growth and yield targets.

b) Assess the nutrient requirements to attain the above and prevent the occurrence of nutrient deficiency.

c) Assess the management level and resources of the estate.

d) Ascertain the most efficient and cost effective fertilisers and applications of fertilisers to meet the nutrient requirements.

e) Compute the economics of the recommendations and expected results.

f) Monitor the outcome including the economic returns.

g) Decide on further action required and repeat the steps if necessary.

iv) Most of these steps should be covered by other lectures in this course but for completeness and comprehensibility of our lecture, we shall briefly discuss them.

2.2) Computation of fertiliser requirement

i) There are several methods commonly used for the formulation of fertiliser recommendations. These include:

a) Critical leaf and/or soil nutrient level method

b) Optimum nutrient ratio method

c) Yield response function method and

d) Nutrient balance method

ii) In actual practice, derivation of fertiliser rates does not rely exclusively on any one method. An integrated approach, which combines the above methods, is usually adopted and AAR is one of its proponents.

iii) Primarily, the nutrient balance method is employed first to compute the nutrient requirements of oil palm in a manuring block. This approach assumes that the oil palm agroecosystem has definite components of nutrient removal (demand) from the system and nutrient return (supply) to the system (Figure 1). The components of nutrient demand are:

a) Growth

b) Yield

c) Nutrient losses through leaching, run-off and erosion

d) Nutrient removed by pest damage and

e) Nutrient non-availability and antagonisms.

The components of nutrient supply are:

a) Nutrient returns from the palms, e.g. pruned fronds

b) Nutrient returns from leguminous covers

c) Rainfall

d) Soil

e) Fertilisers

The basic principle is then to estimate the total demand of the palm and match it with the nutrient supply by the oil palm agroecosystem excluding the fertiliser component. The shortfall between the nutrient demand and supply, which is also called gross nutrient requirements, should be met by fertilisers.

iv) A number of studies have been made to quantify the various components of nutrient demand and supply in the oil palm agroecosystem.

v) The two largest components of nutrient demand are Growth and Yield. They are also the first key steps in an effective fertiliser management scheme as outlined earlier. Thus, it is essential that the agronomist estimates the growth rate and yield trend of a manuring block right from the start. A typical example of the growth rate of oil palm using leaf area as the criterion is shown in Figure 2. Coupled with the leaf nutrient concentrations, the agronomist will be able to estimate the nutrient requirements necessary to attain the expected growth. Similarly, the yield profiles in different regions of Malaysia as illustrated in Figure 3 will provide a clue on the nutrient removal per year from the manuring block which should be replaced by fertiliser inputs.

vi) On the nutrient supply side, available data suggests that atmospheric returns are probably insignificant. However, pruned fronds can provide substantial nutrients to the palms to the tune of 36% for N and 27% for K on poor inland soils in Peninsular Malaysia. In mature oil palm areas, the last component of nutrient supply is soils. Unfortunately, most Malaysian soils including those from Sabah are inherently poor in nutrients particularly N and P (Table 1). Therefore, most of the nutrients required by the palms have to come from fertilisers, usually in mineral forms.

vii) An example of the computation of nutrient balance and fertiliser requirements to sustain 30 t/ha/yr in a mature oil palm field is shown in Table 2. It is assumed that the oil palm is in a steady state and grown on a soil with poor fertility. Under steady state condition, the canopy size remains constant and therefore, the nutrient requirements for canopy growth should be met by the nutrients recycled from the pruned fronds. The final analysis shows that the annual fertilisers needed for each palm to satisfy the gross nutrient requirements totalled 10.75 kg and comprise 4.22 kg Ammonium chloride, 0.97 kg Jordan phosphate rock, 3.59 kg Muriate of Potash and 1.97 kg Kieserite.

viii) While the nutrient balance approach provides the gross nutrient requirement, it does not work out the fertiliser requirements directly. We need information from fertiliser trials to enlighten us on the optimum fertiliser rates and the yield responses. In Sabah, the oil palms respond mainly to N fertiliser followed by K and P fertilisers (Table 3). The response to N generally exceeds 15 % except on Lumisir Family soil. The latter might be attributed to its high inherent soil fertility status as indicated by the yields in the control plots (no fertiliser). K responses are mainly lower than those experienced in Peninsular Malaysia. Again, this can be explained by the relatively high soil exchangeable K status as shown in Table 1. These results strongly imply that the agronomist must know and understand the soil properties in the manuring blocks, not just the soil names, to draw up proper and effective fertiliser recommendations to the estates.

ix) We can also predict the fertiliser efficiency in each trial by plotting the gross nutrient requirements against the fertiliser rates as shown in Figure 4 while Table 4 shows the fertiliser efficiencies in some coastal and inland soils in Peninsular Malaysia. The highest K fertiliser efficiency was in Munchong series soil at 83%. This was due to the poor soil K reserve and good yield response to K fertilization. The lowest fertiliser K efficiency was found in Briah series soil at 19% due to high fertiliser rates and soil K status. In general, fertiliser efficiency is affected by the gross nutrient requirement, imbalanced nutrition, fertiliser rates, soil fertility and nutrient losses.

x) Collating and assimilating the data from fertiliser trials conducted worldwide have enhanced the confidence of the agronomists to extrapolate the results to other sites with similar conditions and combining them with nutrient balance computation, leaf analysis and soil fertility status to produce the fertiliser recommendations.

2.3) Balanced fertilisation

i) High fertiliser rates alone will not always provide optimum economic returns: a balanced fertiliser program is also essential as illustrated in Table 5. Nitrogen increased yield by 49% in the presence of high K rate. Similarly, there was a 25% yield response to K when high N rate was applied. Both N and K also had beneficial effect on the vegetative dry matter production.

ii) Apart from the above, application of K fertiliser will decrease oil to bunch ratio in the absence of N fertiliser (Table 6). However, with sufficient N level, K fertiliser generally increased the oil to bunch ratio to similar level compared to the control.

iii) Positive interactions of K fertiliser with other agronomic practices such as mulching, frequency of application and frond placement have been reported to increase yield between 4% and 14%.

iv) While capitalising on synergistic effects will improve yield and fertiliser efficiency, avoidance of antagonistic effects is also necessary to maximise fertiliser use. For example, high K rates have been shown to depress Mg and B uptakes and might decrease yield.

2.4) Potential nutrient losses and environmental concerns

The recommended fertilisers should be applied in a manner that they are absorbed by the palms at maximum efficiency. This is best done by minimising fertiliser losses in the plantation, which is even more important now in view of the current economic woes. It should also minimise environmental problems if any.

Nutrients may be lost by surface run-off, leaching through the soil profile, nutrients fixation, volatilisation and immobilisation by ground covers in young oil palm. An understanding of these nutrient loss mechanisms is essential to alleviate them and improve fertiliser efficiency.

i) Surface run-off

a) On average 11% of N, 3% of P, 5% of K, 6% of Mg and 5% of Ca applied can be lost in surface run-off alone (Table 7). These results were obtained during a low rainfall year with only 1426 mm on a 9% slope. The most susceptible areas for run-off tend to occur in the harvester's path and along the oil palm rows where the soils are more compacted and the ground vegetation is generally sparse.

b) More recent data obtained by AAR also indicate that the mean run-off losses as percentage of the nutrient applied are within the following ranges: 5-8% N, 10-15% K, 4-6% Mg and less than 2 % for P (Table 8). These results show that soluble nutrients such as N, K and Mg are more susceptible to run-off losses. We further found that nutrient losses via surface run-off are highly dependent on the rainfall pattern at the time of fertiliser application, particularly during the first few rains after application and the antecedent moisture status of the soil. Other equally important factors, which might affect run-off, are the canopy cover, rainfall intensity and quantity, soil characteristics and slope.

ii) Leaching losses

a) Leaching losses during the first four years of oil palm growth (as % of total nutrient applied) have been found to be about 17% N, 10% K and 70% Mg. Losses are substantially reduced to about 3% N, 3% K and 12% Mg when the palms are fully matured (Table 9). The main reasons for the high leaching losses during the early stage of palm growth are probably poor palm canopy cover, less extensive root system and ground covers are generally not well established especially during the first year after planting.

iii) P Fixation

a) Losses due to fixation by the soil involve mainly phosphate fertilisers. The P fixing capacities of some of the common Malaysian soils are shown in Table 10. The amount of P 'fixed' ranged from 208 mg to

1172 mg per kg soil and is related to its clay mineralogy. Although soils with high P fixing capacity improve P dissolution of phosphate rock, they also decrease the soil solution P (intensity), which is required for plant uptake. The general approach is to use less reactive phosphate rock and concentrated application of fertiliser through high rate and banding for these soils.

iv) Volatilisation losses

a) Volatilisation losses are only significant when urea is surface applied, usually over the compacted weeded palm circles. High volatilisation losses in the oil palm field occurred at high rates of fertilization and on light texture soils as shown in Table 11.

b) To increase the efficiency of urea, it should preferably be buried in the ground. However this practice is only suited to small-scale cultivation and unlikely to be practical and economical on a large plantation. Correct timing provides a more suitable means to improve the efficiency of applied urea. For example, volatilisation loss is reduced if urea is applied when moderate rains are expected so that the fertiliser may be washed into the soil.

v) Immobilisation by ground cover in young oil palm

a) Weed growth is strongest in high light conditions in immature plantation. The young palms without extensive root systems are less able to compete for nutrients at this stage, which reduce their nutrient uptake and growth (Table 12). One point of interest is that the total N immobilised by the ground covers commonly exceeded run-off losses and immobilisation by young oil palms.

b) With respect to interrow vegetation management, spraying out the competitive weeds in the interrow vegetation at immaturity and maturity on Selangor series soil (fertile soil) gave the highest oil palm yields after 4 and 6 ½ years respectively. On the other hand, over spraying could lead to bare ground conditions which might cause higher leaching losses, reduce soil moisture and result in poorer soil structure. This in turn may lower FFB yield.

2.5) Economics of fertiliser recommendations

a) The plantation industry is a business proposition and as such, the economic value of a fertiliser is important. This is because the application of fertiliser necessarily increases the cost of production, which has to be at least offset by an increase in yield in order to be profitable.

b) Owing to the delay in the effect of fertiliser on yield, the additional return from the increased yield may be realised in full only after 8 months or even a few years. Furthermore, the magnitude of yield response may vary considerably and the economic comparisons of fertilisers should be based on a discounted cash flow or a similar scheme over the specified period.

c) An example of the economic computation of two sources of fertiliser is provided in Table 13. We choose kieserite versus ground magnesium limestone (GML) to illustrate the point that knowing the agronomic efficiency of a fertiliser as obtained from fertiliser trials is insufficient to recommend its application. Table 13 shows that the agronomic efficiency of GML based on substitution rate was only 74% as effective as kieserite. However, GML was only one-third the price of kieserite at the time of writing. This favoured GML with the consequent relative economic efficiency reaching 2.5. This meant that GML was 1.5 times more efficient compared to kieserite in economic terms.

d) Using the above approach, an expensive fertiliser may be more economical to use if its agronomic efficiency far outweighs its price ratio compared to its competitors.

e) Although the above computation is a standard in economics, of late there are counter arguments which suggest that the selection of a fertiliser should be based on its agronomic efficiency instead of economic efficiency. This contrasting proposition stems from the fact that commodity prices are usually unpredictable and therefore, the economic efficiency can vary substantially. Such view is probably a fallacy since decision-making processes in agriculture, like all businesses, are always done in the face of uncertainty, be it prices or weather etc. Moreover, the use of tender fertiliser prices will allay or negate part of the problems. In plantation agriculture, profit considerations are given the highest priority and therefore, the economic efficiency will always take the centre stage.

2.6) Additional agronomic principles for young palms

The strategy in young palms, apart from the above, should be:

a) To minimise nutrient requirements by maximising returns from the biomass of the previous crops e.g. rubber, cocoa or oil palm by the shredding and no-burn techniques currently practised in many plantations

b) To promote growth of very good leguminous covers with high P and Mg applications and subsequent large nutrient return including N fixed.

Such an approach would reduce fertiliser requirements of the young palms substantially and improve growth and yields, thereby leading to extensive benefits all round.

3.0 Estate and field practices

Getting the fertiliser rates right is only part of the process in an effective fertiliser management in oil palm. We need to apply the fertilisers bearing in mind the potential losses as outlined above. The fertiliser recommendations for an estate, which include the strategies and methods, should answer the following questions:

a) Why apply fertilisers?

b) What fertilisers to apply?

c) Where to apply fertilisers?

d) When to apply fertilisers?

e) How to apply fertilisers?

In fact, these are essential and valid questions which all planters should ask and discuss with their agronomists. It is also the role of the planters to ensure that the fertiliser recommendations are carried out well. As the common adage says "The best fertiliser is the planter's boots and nothing beats walking through the fields".

3.1) Manuring block size

a) The first field practice is to ensure that the manuring blocks are relatively uniform in terms of soil types, terrain, palm sizes, palm age etc. The manuring blocks should be clearly demarcated by roads for ease of management.

b) Of late, there is a discernible move towards larger manuring blocks in the estates with many of them exceeding 100 ha. The main reasons for this are unknown although the undertone is that management will be easier especially for large estates. Such practice, which is a form of sweeping generalisation, is definitely wrong and will make a mockery out of fertiliser management. It can also easily negate the hugh investments in cost, time, manpower and equipment in the preparation of precise fertiliser recommendations.

c) Futhermore, if each manuring block consists of vastly different soil types, terrain etc, then the following four situations may probably occur with a single fertiliser regime:

1) Just sufficient - palms receiving the correct dose of fertilisers

2) Over application - palms receiving too much fertilisers

3) Under application – palms receiving insufficient fertilisers causing nutrient deficiency

4) Imbalance - palms receiving incorrect proportion of fertilisers

Out of these conditions, the last three may result in lower yields and/or profits. They may also cause environmental pollution and land degradation. In fact, good agronomists always regard them as cardinal sins and perhaps, the planters should also adopt the same attitude.

d) On average, a manuring block should not exceed 40 ha as established since the sixties and be at least 80% uniform. With new technology and site-specific fertiliser recommendations, they can be reduced with minimal burden to estate management.

3.2) Accurate information

a) Accurate information of each manuring block and estate kept by the management and data collected by the agronomists with the assistance of the management are necessary for optimum fertiliser recommendations and practices.

b) The information includes the following:

1) Data to compute the nutrient balance including expected growth and yield as described earlier.

2) Site yield potential and actual yield

3) Expected response to manuring

4) Assessments of palm sizes, vigour, deficiency symptoms etc

5) Soil data including analysis, soil types, terrain etc

6) Leaf analysis and vegetative growth measurements

7) Factors affecting fertiliser efficiency

8) Palm age, materials, density etc

9) Climatic conditions

10) Field conditions, eg. weeds, drainage, mulching etc

11) Other relevant data, e.g. planting dates, replanting dates, technique of planting etc.

12) Past fertiliser history including fertiliser rates, sources, timing etc

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

1) formulation of fertiliser recommendations

2) judgement of the performances of the palms and estates

3) early recognition of problems and problematic areas

4) building up a knowledge of the fields

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

d) A point to note is that the data should be collected at the manuring block scale or smaller. It is quite pointless to record say FFB yields from several manuring blocks together or from a planting of 200 ha or more, and yet attempt to make sense out of the data.

e) It is also important that the area of a manuring block should be precise to less than 1.5 %. This is because all productivity figures, and criteria and indicators of palm health and estate performances are based on the areas of the manuring blocks. Thus, it is essential to have a proper surveyed map of the estate done by qualified surveyors. Alternatively, the estate can be mapped using global positioning system (GPS) which is cheaper, easier and faster (Figure 5).

f) The density of palms in each manuring block should be known at all times. Hence, annual palm census should be carried out and any palms which die in the year should be taken out of the record immediately. In some estates, the number of palms in each row is recorded on the first palm of the row along the road. This enable more accurate distribution of fertiliser bags in the fields.

g) Hence, the management must keep an accurate records of the data at the appropriate scale for the benefit of all.

3.3) Strategies to reduce nutrient losses

With the potential large losses of fertilisers in the oil palm agroecosystem, it is only natural that we devise techniques to reduce them and improve fertiliser efficiency. These techniques call for an integration of agronomic practices as briefly described below.

i) Choice of fertiliser

The choice of fertiliser is largely an economic issue, not only in terms of fertiliser prices but also the likely returns from their applications in the fields. Therefore, the properties of the fertilisers and the agronomic conditions in the plantations such as climate, soils and terrain should also be considered.

The choice of fertiliser for oil palm has been covered in previous lectures and therefore, only the pertinent points are discussed for completeness.

a) N fertiliser

There are several sources of nitrogen and the more common ones for oil palm are ammonium sulphate (21% N), ammonium nitrate (26% N), ammonium chloride (25% N) and urea (46% N). Various trials showed little differences in fresh fruit bunch (FFB) yield responses to them except for urea. The latter gives comparable results only under high rainfall conditions and on clayey soils.

b) P fertiliser

An agronomic evaluation of different sources (rock phosphate versus soluble super phosphate) of P fertiliser is shown in Table 14. The results indicated that there was no difference between P sources, although P fertiliser improved palm growth. Nevertheless, the choice of P fertiliser would depend on the cost of fertiliser and the availability of P to meet the demand by the palms and its economic efficiency. For example, water soluble P source is commonly provided to immature palms via compound fertilisers while phosphate rocks are probably more economical for mature palms.

c) K fertiliser

In mature oil palm plantations, the choice of K fertiliser is usually limited to Muriate of potash. However, in view of the current economic situation and high fertiliser prices, other sources such as soil K if it is sufficient (more than 0.5 cmol kg^{-1}) can be used. This is based on a long term trial which showed that after 7 years of K fertilization, there was a substantial build-up of soil exchangeable K (from 0.2 cmol kg^{-1} in the control to 0.8 cmol kg^{-1}) particularly in the palm circle where the fertilisers were applied. Moreover, well-grown mature palms have a large reserve of K in the trunk, which can be utilised. With careful monitoring of the soil K status, reduction in K fertiliser can be made without much adverse effect on the growth and yield of the oil palm in the short term. For example, withdrawal of K fertiliser up to 4 years before replanting did not affect yields on an inland soil.

The oil palm plantation produces large quantities of by-products in processing the fresh fruit bunches (FFB) to palm oil. On average, every tonne of FFB produces about 220 kg empty fruit bunches (EFB). And 1 tonne of EFB contains an equivalent of 15.3 kg of ammonium sulphate, 2.5 kg of Christmas Island rock phosphate (CIRP), 18.8 kg of Muriate of potash and 4.7 kg of kieserite. Therefore, for mature oil palm, 40 t ha^{-1} of EFB applied in the interrows can supply sufficient nutrients to meet the palm requirement for a year. Supplementary fertiliser applications such as CIRP may be required to balance the palm nutrition.

d) Mg fertiliser

The most common sources of Mg fertiliser in Malaysia are kieserite and ground magnesium limestone (GML). These two materials differ greatly in their solubilities and acid neutralising capacities. Kieserite is more water soluble compared to GML and has better agronomic efficiency. However, GML is favoured as a major Mg source for mature oil palm due to its higher relative economic efficiency compared to kieserite. For young palms or when quick availability of Mg is desired, then kieserite should be used.

A word of caution to those who use GML as a source of Mg. GML contains high Ca and if it is over-applied or misused, it can be antagonistic to K uptake by the oil palm. The leaf and soil have to be closely monitored to prevent this detrimental effect from occurring and therefore, its use should be left to the experts only.

e) By-product utilisation

Apart from pruned fronds, the oil palm industry produces large quantities of by-product particularly empty fruit bunches (EFB) and palm oil mill effluent (POME). Both EFB and POME contain substantial amounts of nutrients (Appendix 1) and organic matter which can replenish the soil fertility and meet the nutrient requirements of oil palm. In general, 40 t EFB per ha per year or 450 litres raw POME per palm per year are applied on poor inland soils. Supplementary P and B fertilisers are usually neccessary to balance the palm nutrition.

The selected fertilisers must then be accurately timed and applied in the fields for best results. This involves correct timing of fertilisers, frequency of application and placement of fertilisers as discussed below.

ii) Frequency of fertiliser application

a) Applying K fertiliser once a year is sufficient to sustain the growth and yield of oil palm (Table 15). Increasing the frequency of application up to 6 rounds a year does not improve the yield significantly.

b) However, in most oil palm plantations, the actual frequency of fertiliser application depends on the crop requirement, palm age, ground conditions, types of fertilisers and rainfall. This is to minimise the risk of leaching and run-off losses and ensure that sufficient nutrients are available to meet the palm's need at all times. For example, higher frequency of application is provided to immature palm where palm growth is rapid but the root system is not fully developed. Similarly, only one round of phosphate rock is generally required for mature oil palm due to its good residual value.

c) With the current labour shortage, the aim is to reduce the frequency of fertiliser applications to the minimum without sacrificing on the optimum fertiliser rates and fertiliser efficiency. This is possible via:

    1) Even spreading of fertilisers in the designated areas

    2) A change in the methods of fertiliser application

    3) Proper timing of fertiliser application

    These field practices are discussed below.

iii) Placement of fertilisers

a) Fertilisers should be applied in areas with maximum feeder root distribution to ensure good nutrient uptake, and this varies according to palm age. In the young palms, N fertilisers should be spread evenly over the weeded palm circle close to the palm base and gradually extended to the palm interrows and frond heaps when the canopy has overlapped and good root development is found there.

b) Apart from the harvester's path, the site to apply N and K fertilisers was not critical for mature oil palm above 10 years old due to their extensive and efficient root systems. Therefore, it is advantageous to broadcast N and K fertilisers in the interrrows and over the frond heaps to avoid concentration of nutrients in the palm circles which can lead to higher leaching losses and acidification. Nevertheless, interrow should be free from dense ground vegetation to avoid serious competition for nutrients and water as discussed earlier.

c) Broadcasting of phosphate rock is generally practised for older mature palms as this will increase the likelihood of root contact with rock phosphate particles resulting in better fertiliser efficiency.

d) In hilly terraced areas with mature palms, fertilisers should be broadcast in the terrace itself and between the palms. In areas with platform, the fertilisers should logically be placed around the palms.

e) The proper areas for fertiliser placement are shown in Table 16. However, they should be amended by the agronomist where necessary according to the actual palm status, field conditions and estate resources including workers and equipment.

iv) Method of fertiliser application

a) Fertiliser application is traditionally carried out manually, the fertilisers broadcast over the sprayed palm circle area or other desired areas.

b) Due to labour shortage and poor quality of workers, and compounded sometimes by increased fertiliser rates, some estates have resorted to:

1) employment of contract application gangs

2) application of fertilisers in the afternoons,

3) fixed number of bags of fertiliser applied by each worker;

practices which were discouraged previously due to problems with supervision and discipline.

c) Mechanisation of fertiliser application, such as the use of fertiliser spreader and aerial application, offers some solutions particularly for fully mature oil palms of at least 8 years old when the root systems are adequately developed and spread out. Table 17 shows that mechanised spreading of fertilisers gave similar yields compared to manual applications. The other advantages of mechanisation of fertiliser application are:

1) Lower labour requirement, 4 to 5 times less

2) Lower cost per ha, about 50%

3) Faster coverage of land area per day, about 2.5 to 3.5 times more

4) More even spread of fertilisers and most palms will receive their quota of fertiliser

5) Better timing and less frequent fertiliser applications

There are still many problems associated with mechanisation of fertiliser applications such as maintenance of machine and mechanisation paths, and alternate solutions when the machines breakdown (no workers to manually apply the fertilisers!). There are many papers which discussed these problems and therefore, they will not be deliberated here.

d) For first year planting, AA+ plastic mulch provides a way to reduce the fertiliser application to only once per year. With good and easy supervision during planting, the end results are usually better palm growth and uniformity in the fields. Further work is in progress in this area.

e) Another method of fertiliser application which is being propagated is burying the fertilisers around the palm bases. Again, fertiliser application is reduced to once a year. Results from well conducted trials are unavailable to ascertain its full benefits.

v) Timing of fertilisers

a) For most of the soluble fertilisers, proper timing of fertilisers holds the most promise for improving efficiency. There is evidence in Malaysia to show that run-off losses of K in mature oil palm are markedly reduced if applied in dry months or months after low rainfalls. On the other hand, timing of rock phosphate application is usually less critical because of its low solubility and therefore, lower run-off losses.

b) The general guideline (AAR unpublished) is to avoid fertiliser applications during:

1) Period with high rainfalls of more than 250 mm $month^{-1}$ and low rainfalls of less than 25 mm $month^{-1}$

2) Months with high rain days of more than 15 days $month^{-1}$

3) Months with high rainfall intensity of more than 25 mm day^{-1}

4) Periods when the soil is saturated after continuous rains.

c) Fertiliser applications should also be timed to follow circle-weeding rounds to minimise competition from ground vegetation particularly during the immaturity stage.

d) Fertilisers which are antagonistic in nature with each other such as K, Mg and B should be be applied in the same area at the same time. Similarly, GML should not be broadcast over the K and N fertilisers to avoid K displacement and volatilisation respectively.

3.4) Ordering, delivering and storing of fertilisers

a) Before the planters can implement the fertiliser recommendations, they must have the fertilisers. The tender must specify the date of delivery among others such as fertiliser quality. Fertilisers should be ordered early and in some places at least 3 to 6 months ahead. Hence, the estate management should calculate the total tonnage of each fertiliser in each month of application upon receipt of the manuring report if amendments are not required. A purchase order is then placed for the fertiliser indicating clearly the date of delivery.

b) AAR manuring reports provide the above detailed information of fertiliser tonnages and number of bags of fertilisers in each month (Table 18) to reduce paper work in the estate.

c) A point to note is that fertilisers should always be bought from tested and reliable sources. It is not only important to purchase good quality fertilisers but also be assured of their prompt shipment to the estate.

d) Timing of delivery date will depend on the estate location and logistics. Just in time for fertiliser application should be practised when transport infrastructure is good.

e) The total fertiliser weight and the number of bags should be checked against the delivery and purchase orders and ensure that they tally. A sample of the fertiliser, particularly those that appear dubious or which can be adulterated easily such as GML and rock phosphate, should be sent to the laboratory for analysis as soon as the consignment is delivered. The method of sampling should follow SIRIM standards, MS 417, Part 1, 1994. This is to confirm that the nutrients in the fertiliser meet the specification in the tender and to check for the presence of contaminants. A claim should be made if the fertiliser sample does not conform to expectation.

f) Before the fertilisers are delivered, the estate should ascertain that there is enough space in the store for them. The store should be properly constructed, dry and rain-proof. The fertiliser consignment should be neatly stacked for easy reloading and transferring to the fields for application. It will also reduce wastage, losses and contamination from other fertilisers. Hygroscopic fertilisers such as ammonium chloride must be kept dry to prevent it from caking, which can make application slow, costly and less effective. All lumpy fertilisers should be broken up before application in the fields while those which are severely caked at delivery should be rejected and claimed compensation.

3.5) Organisation of fertiliser application

The procedures in planning and organising fertiliser application for manual system are:

a) Check the type of fertiliser to be applied on the day's operation.

b) Calculate the number of bags of fertiliser required for the area.

c) Check that the necessary transport and labour are available for efficient work. Similarly, roads and bridges should be in good order for the distribution of fertilisers in the fields.

d) Ensure that everyone concerned knows the exact rate per palm and how to apply it.

e) Supply each worker with a container of a suitable size with wide brim and make sure he/she knows how many of scoops of fertiliser to apply per palm.

f) The container or measure should not be too small to avoid too many scoops per palm because it leaves more opportunity for error. Similarly, a large measure will result in poor spread of fertiliser during application. The ideal size is probably one which allows two to three scoops of fertiliser per palm.

g) Distribute the bags of fertiliser at calculated points along the road, harvester's paths etc so that minimum carrying is necessary. This can be achieved with proper road system and intensity, and good map.

h) Keep the gang working as close together as possible for ease of carrying and supervision.

i) Ensure that all empty bags are collected and returned for counting.

j) At the end of each day's operation, the empty bags should be counted and reconciled with the number issued minus those which are returned to stock unused. Maintained a record of this. Unused bags should not be left in the field overnight.

k) Assess the area covered and determine the reason for any surplus or deficit of fertiliser used.

l) Application should be supervised all the time by a conductor at least. Estate managers and Assistant Managers should check as long and as often as possible, and at least at the commencement and end of each day's work. This is to ascertain that the correct areas and procedures are followed and to reconcile the figures submitted by the staff on work done.

m) Minor changes to the above procedures are necessary for mechanised spreader system but the basic principles remain the same.

3.6) Supervision

a) Good supervision is tantamount the key to successful implementation of the fertiliser recommendations, be it in manual or mechanised application. 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.

b) The importance of close supervision during fertiliser application is underscored in the example provided in Table 19. 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.

c) This a clear case of uneven fertiliser application due to poor supervision in a huge new project in West Kalimantan. With uniform fertiliser application throughout the field, FFB yields could increase by 52%.

d) Thus, there is no substitute for good and meticulous supervision of field work in the estate.

3.7) Feedback

a) Feedback is one of the keys to successful implementation of the fertiliser recommendations. This is because the responsibility of fertiliser management does not lie with the agronomist alone but ultimately with all concerned.

b) Some of the essential feedbacks are:

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

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

3) 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.

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

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

6) 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.

3.8) Common mistakes in fertiliser applications

a) Many mistakes can happen during fertiliser applications. Some of the more common ones are:

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

2) Not all palms received their quota of fertiliser or some palms are not applied with fertiliser, i.e. roadside palms receive more fertiliser compared to those in the middle of the field.

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

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

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

6) Fertiliser applied without using calibrated measures.

7) 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.

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

b) The management should always watch out for these errors and prevent them from occurring in the estate.

4.0 Criteria and indicators of palm health (fertiliser recommendations)

The planter's boots may be the best fertilisers but walking around the fields is meaningless if the person does not know what to look for nor understand the purpose. We hope we have covered the latter adequately and shall now briefly discuss the former.

Many criteria and indicators of palm health have been developed over the years and six of the most important ones are:

a) Uniformity of palms

b) FFB yields

c) Canopy sizes

d) Leaf nutrient concentrations

e) Soil fertility

f) Field conditions

They also reflect the management standards and inputs in the estates and head-offices.

4.1 Uniformity of palms

i) Many factors can cause poor uniformity of palms in the fields. One of the most common is ineffective fertiliser management. This is again well exemplified by the coefficient of variations (CV) between blocks as provided in Table 19.

ii) CV is a mesure of uniformity and the lower it is the better. Results showed that block 3, which is nearest to the road, had the lowest CV. Thus, fertiliser inputs can narrow the variation in soil fertility leading to better palm uniformity.

iii) Furthermore, there are indications that where palms were better grown due to proper fertiliser management, the annual yield fluctuations may be reduced substantially (Table 20). This will not only ease the management of palms and mills but also the marketing of palm oil.

4.2 FFB yields

i) Every effort and input in the plantations should be geared towards producing the optimum or maximum yields at all times.

ii) However, it is a common mistake to take the FFB yield at face value and worse still, to use it to judge estate performance. It is most unacceptable or untenable to praise the achievement of say 26 t/ha/yr in an ideal area and condemn the attainment of say 22 t/ha/yr in a poor soil such as Malacca series (shallow lateritic soil). On the other hand, good yield is always an excellent portrayal of management and inputs.

iii) To overcome this dilemma or paradox, AAR has furthered the concept of site yield potential and in fact, has quantified it. The site yield potential is the maximum yield achievable given the site characteristics such as soil properties, climate and resources. By comparing the actual yield against its site yield potential one can objectively judge the performances of the palms and estates, and separate to a large extent the management and agronomic limitations (Table 21). Appropriate actions can then be implemented to correct any deficiency.

4.3 Canopy size and vigour

i) FFB yield is a direct function of canopy size and vigour i.e. healthy palms produce optimum FFB yield. Healthy palms are also more efficient in absorbing nutrients from the soils and fertilisers, and generally less susceptible to pests and diseases. It is therefore important to maintain the expected growth rate which commensurates with the prevailing environmental conditions and planting materials.

ii) A point to note is that palms grown on poorer soils will tend to maintain higher vegetative dry matter, e.g. frond dry weight, compared to those on richer soils. This phenomenon is also known as the “Overflow Hypothesis”, which was first suggested by Corley and co-workers in the seventies.

iii) Palms with large canopies will suppress weed growth and reduce weeding requirements. It may also reduce erosion and run-off losses by trapping some rain-water and breaking the fall of rain-drops (reducing the velocity).

4.4 Leaf nutrient concentrations

i) The leaf nutrient concentrations are usually taken from the pinnae of Frond 17 for mature palms and Frond 1, 3 or 9 for younger palms. It is generally used for diagnosis purposes such as the identification of nutrient deficiency and disorders. Various methods have been developed to interpret the leaf analysis results such as critical leaf nutrient concentrations and nutrient ratios. Whichever method is used, one should always remember that the leaf nutrient concentrations are influenced by many factors. Hence, long term trend and knowledge of the fields and management practices are essential to make sound and valid interpretations of the data.

ii) The leaf nutrient contents when combined with the canopy sizes can be used for prognosis purposes and prevent nutrient deficiency and disorders from happening.

iii) Perhaps, the most important use of leaf analysis results is early detection of potential nutrient imbalance which is usually not visibly exhibited by the palms. Instead, yield decline will be experienced if it occurs as discussed earlier.

4.5 Soil fertility

i) It is a common mistake to assume that soil fertility is only related to soil nutrients. In actual fact, it is a combination of all soil properties including among others, texture, mineralogy and terrain. The soil fertility determines the quantity and rate of soil nutrients and fertilisers that are available to the palms.

ii) Just like leaf analysis, interpretation of soil nutrient data has been a particularly difficult and because of:

    a) Subjective views on what are desirable soil nutrient levels for oil palm, and the objectives of interpretation are often confused with the individual perception of the risk of being wrong.

    b) non-standard analytical methods

    c) seasonal variation in soil nutrient contents

    d) most fertiliser trials do not include soil analysis results.

Thus, soil test interpretation usually follows some common philosophies:

a) Build-up and maintenance philosophy (fertilising the soil). The idea is to increase the soil nutrient levels in 1 or 2 years to high soil test levels. Subsequently, in each year we add the expected quantities of nutrients removed by the palms regardless of soil analytical results (Figure 6).

b) Sufficient level philosophy (fertilising the crops). The objective is to add enough nutrients to produce the economic or yield goal of the producer. No fertiliser is recommended if the soil test is at the level where no economic yield response is expected.

c) Optimum cation saturation ratio philosophy (balanced nutrition). The belief is that for each crop there is a specific cation ratio which provides an optimum soil condition for maximum production.

d) Over-fertilisation philosophy (risk preference). This is derived from the fact that response curves are steeper below the economic optimum application than above (Figure 6). Thus, increasing the recommended fertiliser rate beyond that indicated by the experimental data to compensate for the fact that losses to the planters from using too little fertiliser are greater than those from adding more fertiliser than is needed. This philosophy also ensures that if the season is a good one, the economic returns will not be sacrificed for lack of nutrients.

Interestingly, these philosophies do not work in most situations on an individual basis. However, when used together or in combination, they can form a sound scientific technique to interpret soil analytical data for manuring recommendations and long-term soil fertility management for optimum palm health.

iii) Therefore, the soil fertility should be regularly monitored and maintained to ensure sustainability of oil palm. Soils can be treated as a bank of nutrients for the palms, the more fertile the better, be it natural or man-made. But over enrichment of the soils must be avoided to prevent environmental pollution, toxicity to the palms and high costs.

4.6 Field conditions

i) Poor field conditions, be they inaccessibility, inadequate drainage, strong weed competition etc., are good indicators of bad management and inputs. Even if the palms seem satisfactory at the moment, they will not be if the conditions are allowed to persist. Thus, field conditions should be maintained to allow good accessibility for inputs e.g. fertilisers and evacuation of crops, and reduce weed competitions as discussed earlier. This will improve fertiliser use efficiency.

ii) Field conditions also include the palm conditions and fertiliser scorch, weedicide spray damage to the lower fronds, beetle damage to the canopy etc should be prevented to provide optimum growth environment to the palms, particularly at the immature stage. AA+ plastic mulch can reduce weedicide spray damage to the lower fronds in the first year of planting because circle spraying is not required.

iii) Presently, there is little knowledge of the interactions between weedicides and nutrients. Over-zealous use of weedicides and different types of weedicides particularly those with few informations on their effects on oil palms should be discouraged.

5.0 Summary and conclusion

a) Good fertiliser management is the key to high productivity and efficiency in most oil palm plantations. However, its benefits go beyond maintaining healthy palms and yields. It is also a pre-requisite for the sustainability of oil palm and its competitiveness in vegetable oil market and other businesses, particularly in the face of labour shortage and environmental concerns.

b) Effective fertiliser management involves three key aspects: appreciating the agronomic principles of fertilisation and fertiliser management, proper field practices and understanding the criteria and indicators of palm health.

c) The ability of the agronomist to advise reliably on amounts of fertilisers to use and techniques to reduce losses are basic requirements underlying all the efforts to minimise use of labour for fertiliser applications and protecting the environment.

d) Ultimately, it is the planters who have to ensure that the fertiliser recommendations and field practices are implemented well.

e) Effective fertiliser management involves everyone in the plantation, from the workers to the top management. It makes each of us a significant player in the industry.

f) Further developments in fertiliser management are necessary in the near future to achieve its goals. We should be ready for them and appreciate that the survival of an organisation often revolves around its ability to understand and effectively deal with change. However, the temptation to jump at miraculous claims to survive in future must be resisted.

g) A final remark: the pride and joy of all planters is when we see acres and acres of healthy oil palms and can proudly exclaim, “We are one of those who are responsible for such beautiful and profitable sight”.

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Table 1: A summary of soil chemical properties in the B horizons (508 samples) of common soils in Sabah, Malaysia.

Parameter	Mean	Minimum	Maximum	Unit of parameter	Standard error
pH	4.41	3.40	7.2	-	1.02
Organic C	0.47	0.07	33.0	%	0.07
Total N	0.07	Trace	0.40	%	0.01
Total P	149	15	874	$mg\ kg^{-1}$	4.39
Available P	2.18	Trace	38.5	$mg\ kg^{-1}$	0.13
Exchangeable K	0.20	Trace	1.00	$cmol_{(+)}\ kg^{-1}$	0.01
Exchangeable Ca	1.64	Trace	24.9	$cmol_{(+)}\ kg^{-1}$	0.16
Exchangeable Mg	2.39	0.01	29.9	$cmol_{(+)}\ kg^{-1}$	0.17
CEC	14.53	1.30	52.3	$cmol_{(+)}\ kg^{-1}$	0.34
Base saturation	23.36	0.45	100	%	1.24

Source: Goh *et al*. (1998).

Table 2: An example of nutrient balance and fertiliser inputs required to sustain 30 mt FFB yield per ha per year in mature oil palm.

Types	Components	Nutrients (kg/palm/yr)			
		N	P	K	Mg
Nutrient demand	Trunk	42.4	4.1	121.6	10.2
	FFB	99.1	15.6	129.6	33.3
	Run-off	15.2	1.0	21.6	2.1
	Leaching	3.4	0.9	6.3	3.4
	Erosion	2.4	Trace	Trace	Trace
	Total 1	162.5	21.6	272.9	49.1
Nutrient supply	Rainfall	17.0	2.4	31.6	4.8
	Total 2	17.0	2.4	31.6	4.8
Nutrient inputs	Nutrient required = Total 1 – Total 2	145.5	19.2	247.6	44.3
	Fertiliser types	AC	JRP	MOP	KS
	Fertiliser equivalent	4.22	0.97	3.59	1.97

Note: AC denotes Ammonium chloride, JRP denotes Jordan rock phosphate, MOP denotes Muriate of Potash and KS denotes kieserite.

Source: Ng *et al.* (1999)

Table 3: Yield responses (t FFB/ha/yr) of oil palm to N, P and K fertilisers in Sabah, Malaysia.

Soil types	FAO units	N			P			K		
		-	+	Diff (%)	-	+	Diff (%)	-	+	Diff (%)
Kumansi	Haplic Acrisols	23.6	31.2	32.2	27.9	28.7	2.9	27.5	29.4	6.9
Batang	Ferric Acrisols	28.9	33.8	17.0	31.1	32.7	5.1	-	-	-
Lumisir	Ferric Acrisols	27.9	30.0	7.5	29.1	29.2	0.3	26.4	30.3	14.8
Koyah[1]	Dystric Gleysols	21.1	28.0	32.7	25.3	25.6	1.2	24.8	26.6	7.3
Inanam[1]	Gleyic Acrisols	16.7	20.4	22.2	17.0	20.8	22.4	17.6	20.0	13.6
Buran	Gleyic Luvisols	29.1	33.7	15.8	31.1	31.9	2.6	30.9	32.6	5.5

1: Sites were subjected to fluctuating water table and seasonal flooding.
Note: diff denotes difference; - denotes without respective fertiliser; + denotes with respective fertiliser
Source: Goh and Teo (1997).

Table 4: Estimated K uptake from fertiliser and K fertiliser efficiency in five soil types in Peninsular Malaysia.

Soil series	Soil Taxonomy	Fertiliser K uptake (kg/palm/yr)	K fertiliser efficiency (%)
Selangor	Typic Tropaquept	0.57	42
Briah	Typic Tropaquept	0.64	19
Munchong	Xanthic Hapludox	1.50	83
Kuantan	Typic Hapludox	0.98	54
Malacca	Petroferric Hapludox	0.78	54

Source: Recomputed from Teoh and Chew (1988).

Table 5: 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 6: Effect of NK interaction on oil to bunch ratio (%) in Malaysia.

Soil series	Soil taxonomy	Potassium levels	Nitrogen levels			LSD
			N0	N1	N2	
Bungor	Typic Paleudult	K0	27.1	23.4	24.0	3.0
		K1	25.0	24.8	24.2	
		K2	23.5	24.6	25.4	
Rengam	Typic Paleudult	K0	26.9	25.6	24.8	3.0
		K1	23.7	24.6	21.3	
		K2	22.8	23.5	24.1	

Source: After Foster et al. (1988)

Table 7: Mean nutrient losses through run-off water.

Position in field	Nutrient lost as percent added.					
	N	P	K	Mg	Ca	B
Oil palm row	13.3	3.5	6.0	7.5	6.8	22.9
Harvest path	15.6	3.4	7.3	4.5	6.2	33.8
Pruned frond row	2.0	0.6	0.8	2.7	0.8	3.3
Pruned frond/harvest path	6.6	1.4	3.5	2.2	3.4	12.5
Average for the field	11.1	2.8	5.0	5.6	5.2	20.7
Nutrients applied (kg ha^{-1})	90.2	52.0	205.9	32.8	78.9	2.4

Source: Maene et al. (1979)

Table 8: Mean net nutrient losses in the oil palm ecosystem via surface run-off and eroded sediment on Rengam series (Typic Paleudult) soil.

Nutrient	Net annual losses (kg $ha^{-1}y^{-1}$)			Net loss as % of applied fertiliser*
	in runoff	in eroded sediment	Total	
N	4.5 – 7.2	0.5 – 0.8	5 – 8	5 – 8
P	0.7 – 1.1	0.5 – 1.3	1.2 – 2.4	0.8 – 1.6
K	20.8 – 33.0	Trace	21 – 33	9.8 – 15.3
Mg	3.6 – 6.8	0.1	3.7 – 6.9	4.1 – 7.6

* Mean (1992 – 1994) fertiliser input was equivalent to: 101 kg N, 145 kg P, 215 kg K and 90 kg Mg ha^{-1} y^{-1}.

Source: Kee and Chew (1996)

Table 9. Leaching losses of nutrients measured in an oil palm lysimeter study.

Palm age (y)	Leaching losses as percentage of applied nutrients			
	N	P	K	Mg
1-4	16.6	1.8	9.7	69.8
5-8	1.2	1.6	2.5	11.5
9-14	30	15	2.9	15.5

Source: Foong (1993)

Table 10. P sorption capacity and mineralogy of some common Malaysia soils.

P Sorption	Soil	Orders	P fixed (mg kg^{-1})	Kaolinite (%)	Gibbsite (%)	Fe_2O_3 (%)
	Marang	Ultisol	208	n.d.	-	0.3
	Lanas	Ultisol	247	5.6	-	0.6
Low	Rengam	Ultisol	308	8.6	0.6	1.3
	Tebok	Ultisol	383	11.8	-	0.2
	Serdang	Ultisol	396	13.0	0.2	0.9
	Tok Yong	Ultisol	450	16.8	3.2	2.9
	Harimau	Ultisol	568	16.0	1.0	3.3
	Jempol	Oxisol	571	4.2	-	1.3
Moderate	Bungor	Ultisol	663	9.0	-	2.1
	Lanchang	Ultisol	668	38.6	-	5.2
	Beserah	Ultisol	710	22.9	6.3	2.7
	Munchong	Oxisol	735	31.8	7.7	5.8
	Sg. Mas	Oxisol	928	19.9	0.6	10.0
Strong	Prang	Oxisol	985	40.2	4.0	4.8
	Segamat	Oxisol	1084	33.8	-	7.4
	Kuantan	Oxisol	1172	21.1	9.8	18.8

Source: after Tessens and Shamshuddin (1983)

Table 11. Urea Volatilisation losses (%) on various soils under oil palm

N rates	Silty clay soils		Sandy clay soil		Sandy clay loam	
	at 3 days	at 7 days	at 3 days	at 7 days	at 3 days	at 7 days
250kg N/ha.	29	29	27	38	35	42
500kg N/ha.	38	42	35	45	38	48

Source: Chan and Chew (1984)

Table 12. Dry matter production and nutrient immoblized by Ground Covers in young oil palms.

Vegetation	Dry matter production (kg ha^{-1})	Nutrients immobilised (kg ha^{-1})				Remarks
		N	P	K	Mg	
Grasses	15098	109	19	156	29	Selangor series @ 20mths after planting
Grasses [1]	10437	90	16	128	22	Serdang series @ 12 mths after planting.
Mikania [1]	5986	76	15	120	11	Planted as cover Serdang series @ 12 mths.
Ischaemum muticum [2]	11390	73	6	188	9	5 year old palm.
Ischaemum muticum [2]	12240	84	-	-	-	1 year old palm.
Asytasia gangetica [3]	7300	181	-	-	-	120 days in open conditions.
Asystasia gangetica [3]	4300	142				120 days in shade.

Sources:
1. Han and Chew (1982)
2. Teo et al. (1990)
3. Quah (1997)

Table 13. The relative agronomic and economic effectiveness of GML and Kieserite using oil palm as a test crop.

Parameters	Methods	Results
Relative yield (%)	$\frac{FFB_{GML}}{FFB_{Ks}}$ x 100 at the same fertiliser rate	97.8%
Relative yield Index (%)	$\frac{FFB_{GML} - CONTROL}{FFB_{Ks} - CONTROL}$ x 100 at the same fertiliser rate	83.3%
Substitution rate (SR)	$\frac{\text{RATE OF Ks}}{\text{RATE OF GML}}$ to produce the same yield	0.74
Price ratio (PR)	$\frac{\text{PRICE OF GML}}{\text{PRICE OF Ks}}$ per unit MgO	0.30
Rel. economic efficiency	$\frac{\text{SUBSTITUTION RATE (SR)}}{\text{PRICE RATIO (PR)}}$	2.47

Ks denotes Kieserite
GML denotes Ground Magnesium Limestone

Source: Goh et al., (1998)

Table 14: Agronomic evaluation of phosphate fertiliser and method of application on Oil palm seedlings at 14 months old.

Source	Method	P Rate (g bag^{-1})	Diameter (cm)	Height (cm)	Frond/ palm	Leaf area (m^2)	Length (cm)	Dry weight (g)	Frond produced in 4 months
Nil	-	0	6.8	127	15.9	0.7	81.5	32.3	4.5
CIRP	Mixed	0.2	8.2	167	16.9	0.9	101.4	45.9	5.1
CIRP	Mixed Surface	0.2 +0.3	8.3	159	17.6	1.0	100.3	47.5	5.3
CIRP	Surface	0.3	7.3	156	16.3	0.9	92.2	41.8	4.3
Super phosphate	Surface	0.3	7.7	164	16.3	0.9	97.7	43.6	5.3
Super phosphate	Surface	0.6	7.7	149	16.7	0.9	93.4	40.0	5.2
Mean			7.7	154	16.6	0.9	94.4	41.8	5.0
SE			0.3	26	0.5	0.8	5.5	4.0	0.4

Source: HRU Annual Report, 1973

Table 15: Effect of frequency of fertiliser application on oil palm yield in Malaysia.

Soil series	Soil taxonomy	Unmanured	Frequency of application (t $ha^{-1}y^{-1}$)				
			F1	F2	F3	F4	F5
a. Munchong	Typic Haplorthox	13.5	18.7	19.6	18.4	-	-
b. Rengam	Typic Paleudult	-	-	23.9	-	24.5	-
c. Seremban	Lithic Hapludult	26.6	-	-	-	27.3	27.6

Source: a) After Teoh and Chew (1985)
b) After Foster and Tayeb (1986)
c) After Chan et al. (1993)

Note: F1 – once in 2 years.
F2 – once a year
F3 – Twice a year
F4 – 3 times a year
F5 – 6 times a year

Table 16: Proper placements of fertilisers in oil palm plantations.

Palm age	Type of fertiliser	Placement area
Immature (≤ 3 yr)	All	Spread evenly within weeded circle around palm.
Young mature (4-9 yr)	N, K, B and kieserite	Broadcast evenly within weeded circle but further from the palm (about 1 metre)
	GML and Rock phosphate	Broadcast just outside and around the palm circle.
Fully mature (≥ 10 yr)	All except urea, kieserite and B	Broadcast evenly in the interrows and over the frond heaps.
	Kieserite, B and urea	Broadcast evenly within the weeded circle but about 1 metre away from palm base.

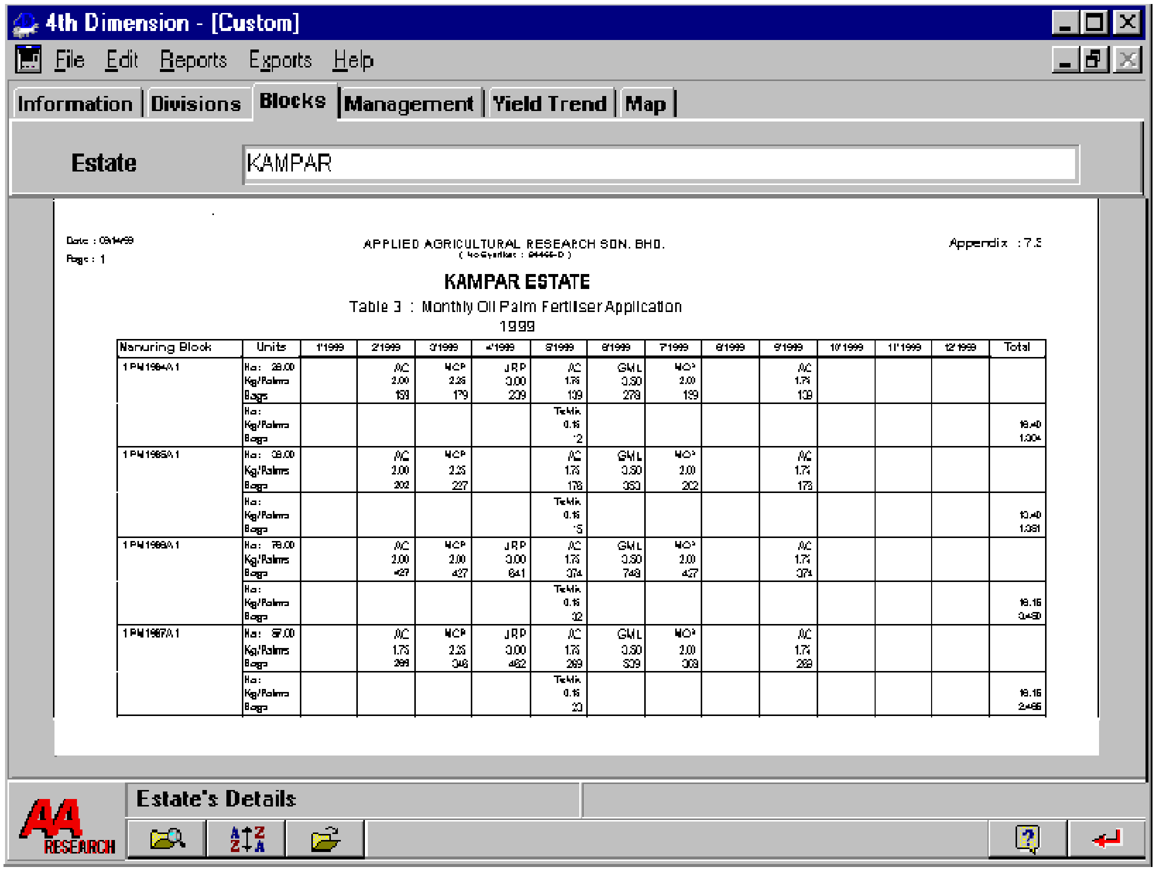
Source: Goh et. al. (1993)

Table 17: Comparison of FFB yield (t/ha/yr) and fertiliser application methods in oil palm.

Methods	Fertiliser regime		Mean
	1	2	
Aerial	23.0	24.7	23.8
Manual	23.9	25.0	24.4
Mechanised	25.2	25.3	25.2
Mean	24.0	25.0	(S.E. = 0.5)
Control			18.1

Note: Regime 1: 2.5 kg Ammonium sulphate/palm/year and 2.5 kg Muriate of Potash/palm/yr.
Regime 2: Twice regime 1.
Source: Modification of work done by Lim and Chan (1992)

Table 18: AAR fertiliser recommendations and schedules including the tonnage of fertilisers and number of fertiliser bags required for each field in an estate



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Appendix : 7.5

KAMPAR ESTATE

Table 3 : Monthly Oil Palm Fertiliser Application

1999

Manuring Block	Units	1/1999	2/1999	3/1999	4/1999	5/1999	6/1999	7/1999	8/1999	9/1999	10/1999	11/1999	12/1999	Total
1 PM1984A1	Ha: 28.00 Kg/Palms Bags		AC 2.00 159	MOP 2.25 179	JRP 3.00 239	AC 1.75 139	GML 3.50 278	MOP 2.00 159		AC 1.75 139				
	Ha: Kg/Palms Bags					TeMix 0.15 12								18.40 1,304
1 PM1985A1	Ha: 38.00 Kg/Palms Bags		AC 2.00 202	MOP 2.25 227		AC 1.75 178	GML 3.50 353	MOP 2.00 202		AC 1.75 178				
	Ha: Kg/Palms Bags					TeMix 0.15 15								10.40 1,351
1 PM1986A1	Ha: 78.00 Kg/Palms Bags		AC 2.00 427	MOP 2.00 427	JRP 3.00 641	AC 1.75 374	GML 3.50 748	MOP 2.00 427		AC 1.75 374				
	Ha: Kg/Palms Bags					TeMix 0.15 32								18.15 3,450
1 PM1987A1	Ha: 57.00 Kg/Palms Bags		AC 1.75 289	MOP 2.25 348	JRP 3.00 462	AC 1.75 289	GML 3.50 539	MOP 2.00 308		AC 1.75 289				
	Ha: Kg/Palms Bags					TeMix 0.15 23								18.15 2,465

Table 19: Effect of uneven fertiliser applications on the early yields (8 months of crop) of six years old oil palm in Kalimantan, Indonesia.

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 20: Yearly variations in FFB yields on different soil types in Malaysia.

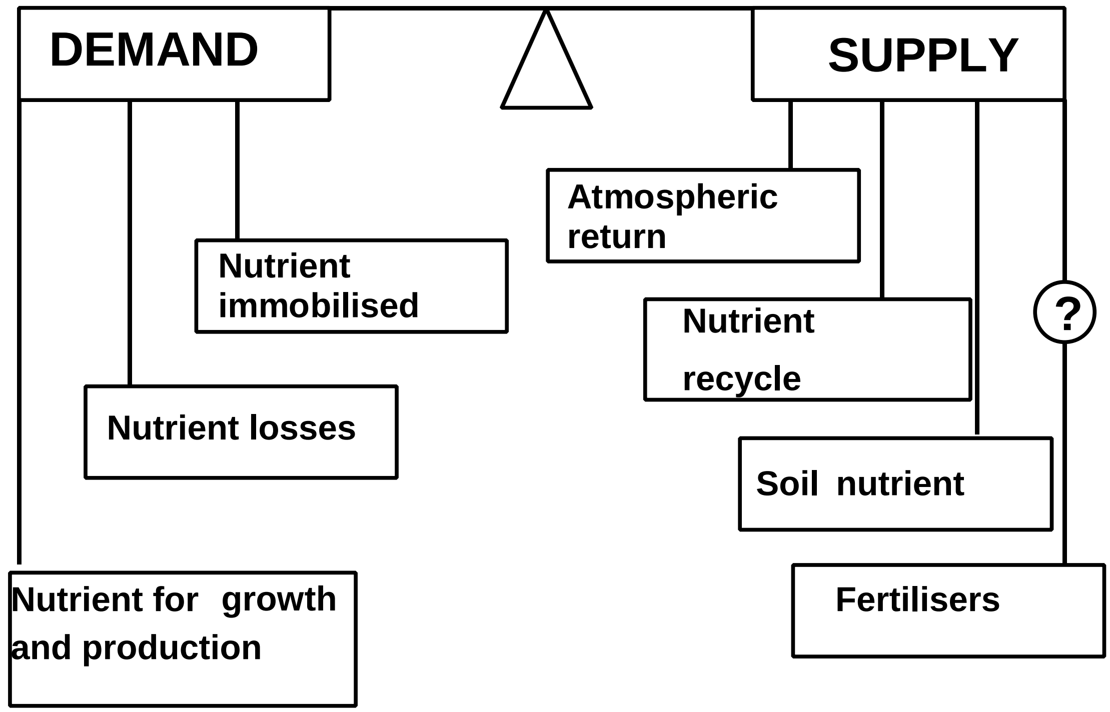
Soil	Treatment	Year after treatments							Mean	SD	CV(%)
		3	4	5	6	7	8	9			
Briah	CONTROL OPTIMUM	33.0 33.0	40.0 33.0	27.0 30.5	20.0 29.0	21.0 26.0	23.0 29.0	22.0 27.0	25.6 30.6	5.1 4.4	20.0 14.2
BERNAM	CONTROL OPTIMUM	21.5 27.0	19.5 24.5	9.5 17.0	15.0 23.5	11.0 17.0	12.0 19.0	12.0 24.0	14.4 21.7	4.2 3.7	29.3 17.1
SOGOMANA	CONTROL OPTIMUM	31.0 34.5	27.0 36.0	22.5 28.0	24.5 31.0	26.5 31.0	20.0 32.0	31.5 32.0	26.1 32.1	3.9 2.4	15.0 7.5
RENGAM	CONTROL AMMONIU M SULPHATE	23.8 26.1	22.0 27.7	17.9 28.3	21.9 26.2	25.9 34.4	21.5 32.4	17.0 23.0	21.4 28.3	2.9 3.6	13.5 12.8
MALACCA	CONTROL OPTIMUM	11.0 20.5	14.0 22.5	12.0 20.0	11.5 24.0	16.0 26.0	18.0 37.0	13.0 27.5	13.0 25.4	2.4 5.4	18.5 21.2

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

Table 21: Examples of some criteria to categorise the yield performance of each field in an oil palm estate.

Actual yield/SYP (%)	Management standard	Agronomic problems	Category
> 90	Good	Minor	Good
80 – 90	Satisfactory	Minor	Satisfactory
70 – 80	Fair	Moderate	Fair
50 – 70	Poor	Serious	Poor
< 50	Very Poor	Serious	Very Poor

Figure 1 : Components of nutrient balance in oil palm.



(From Ng 1977)

Figure 2: Expe
in Peninsular Malaysia be

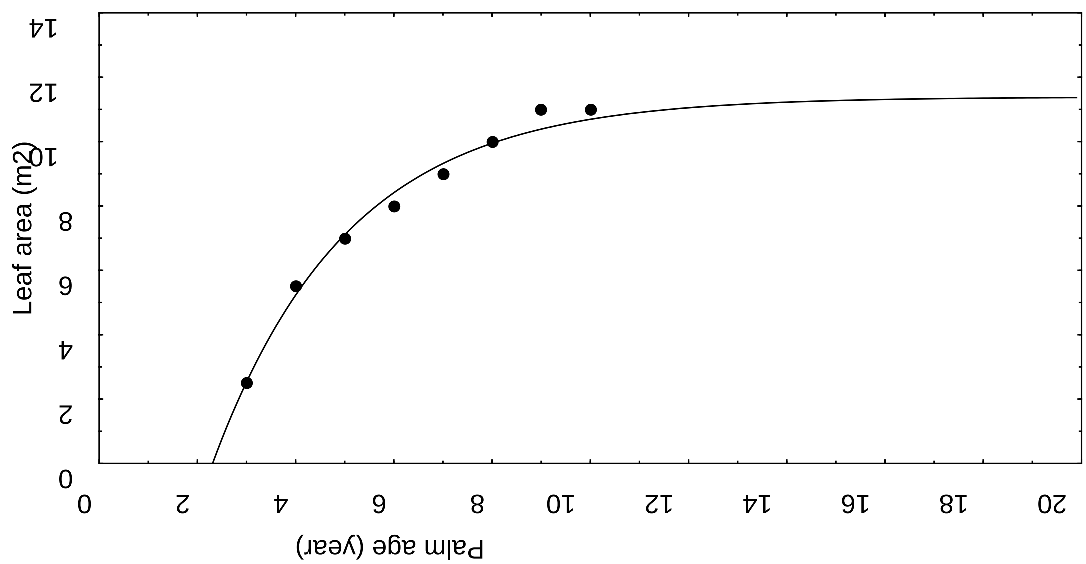
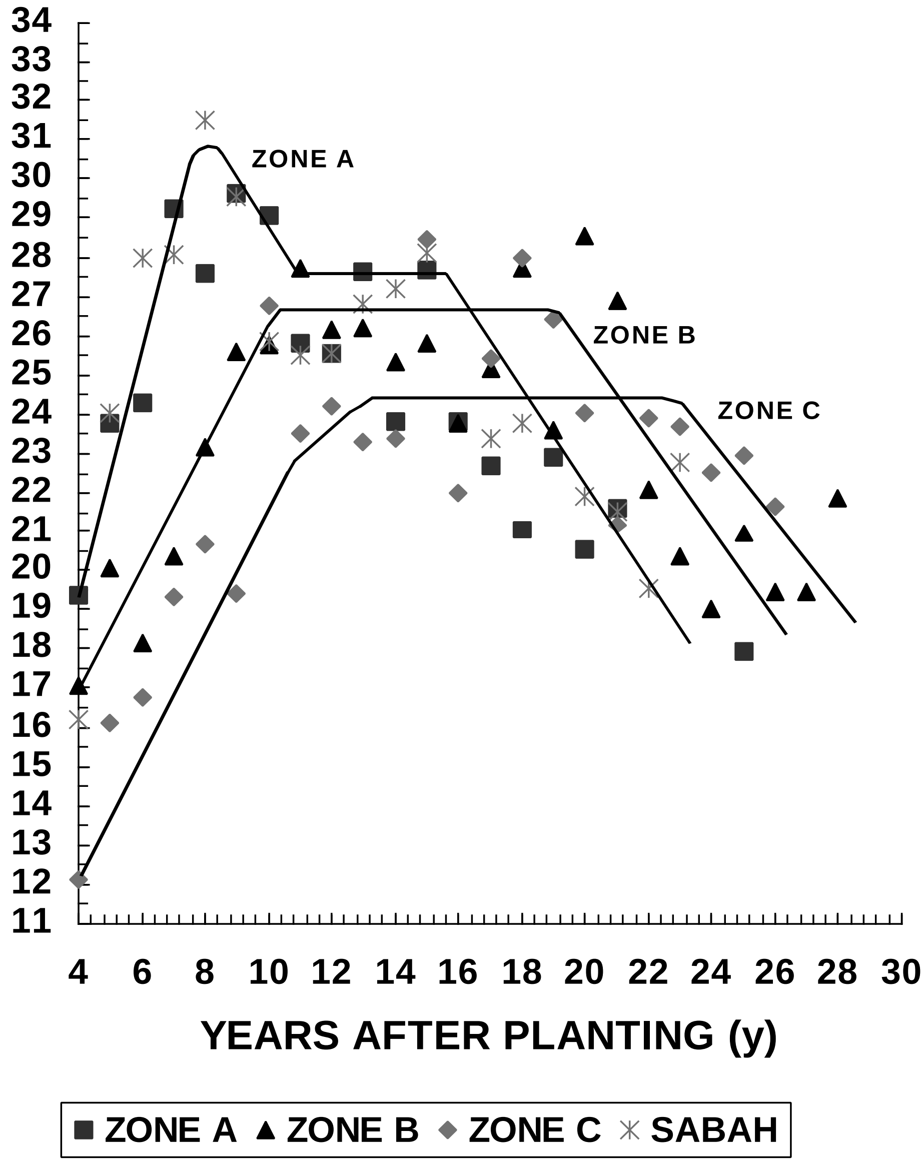


Figure 3: Yield profiles of oil palm in different regions of Malaysia.



Note: Zone A – Region with no distinct dry season including most parts of Sabah

Zone B – Region with occasional dry seasons

Zone C – Region with distinct dry season

Source: Goh *et al.* (1994)

Figure 4: Effect c
on Rengam series soil i

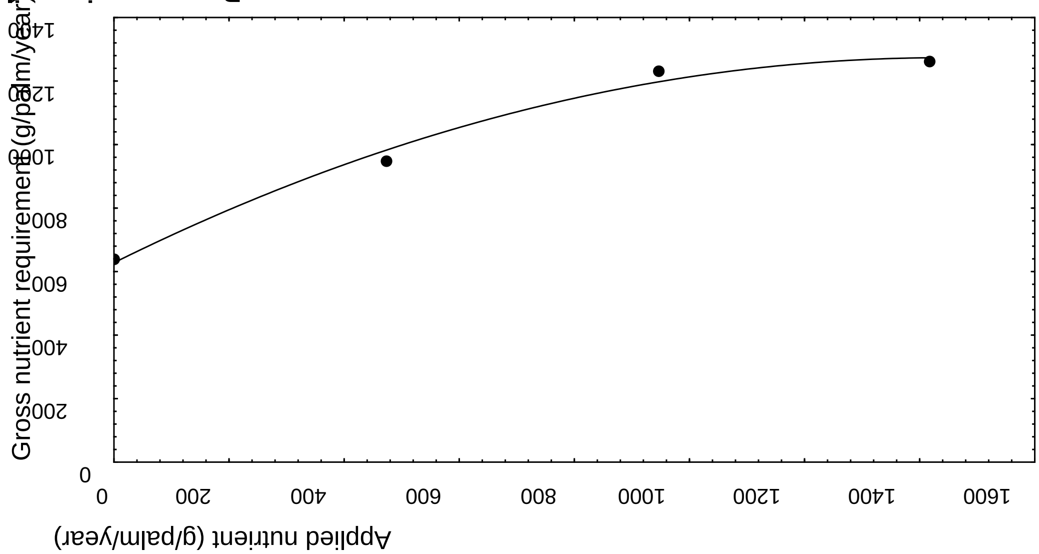


Figure 5: Quality & Accurate Map With GPS and Desktop Mapping GIS

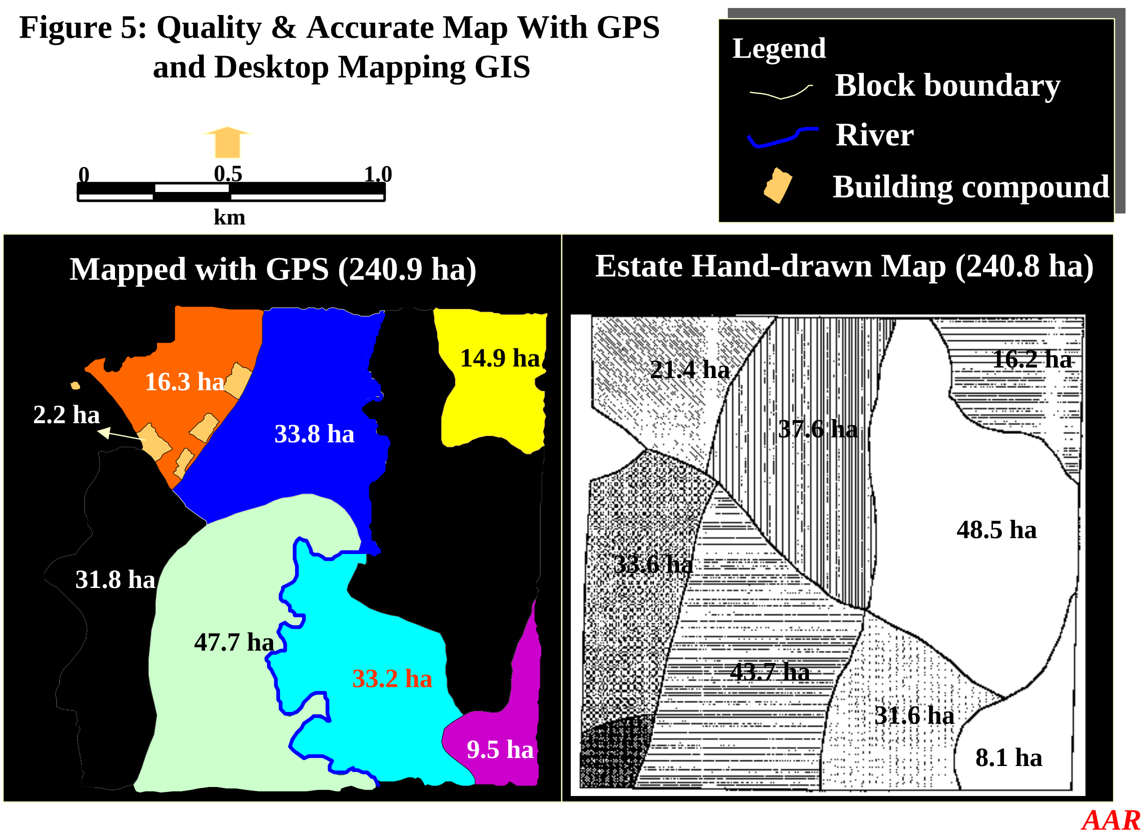


Figure 6: Relationship between relative yield and fertiliser P response as influenced by initial yield response and maintenance requirement (after Black).