Canopy Management to Optimize Yield

Helmut von Uexkull

Hege/strasse 2,53177 *Bonn, Germany. E-mail: H.R.von.Uexkuell@t-online.de*

Ian E. Henson

Malaysian Palm Oil Board (MPOB), Biological Research Division, No 6 *Persiaran Institusi, Bandar Baru Bangi, Kajang, Selangor* 43000, *Malaysia. E-mail: henson@mpob.gov.my*

Thomas Fairhurst

Potash & *Phosphate Institute/Potash* & *Phosphate Institute* of *Canada* - *East* & *Southeast* Asia *Programs,* 126 *Walten Estate Road, Singapore* 287599. *E-mail: tfairhurst@eseap.org*

INTRODUCTION

Proper canopy management is a key aspect of yield maximization in oil palm. The supply of carbohydrates (CHP) for vegetative and generative growth is governed by the size of the total green leaf surface and the efficiency with which the canopy converts solar radiation into CH_20, referred to as conversion efficiency (Squire, 1984) or canopy efficiency *(e)* (Breure, this volume).

Canopy management is not just an issue requiring inputs from agronomists, who may select a suitable planting density and provide guidelines on pruning. Planters must also develop the skill to assess the palm canopy and identify the symptoms of excessive frond removal, inter-palm competition or insufficient canopy development and implement nec essary changes in canopy management (pruning, thinning, fertilizer application). In this chapter we will discuss some of the practical aspects of selecting a suitable planting density and how to maintain an optimal canopy throughout the life-span of a field of palms.

MANAGEMENT FOR OPTIMAL LEAF AREA INDEX (L)

The leaf area index *(L)* describes the ratio of leaf area to ground area and is a standard method to assess the size of crop canopies. The optimal *L* may be defined as that which gives the largest yield. The relationship between yield, vegetative growth and *L,* and the derivation of optimum *L* for oil palm has been described by Corley (1973), Breure (1988) and Breure (this volume).

The optimal *L* for yield of oil palm is not a fixed value but is site-specific and varies from 5-7 depending mainly on factors such as:

- Hours of effective sunshine;
- The day: night temperature gradient;
- Soil moisture regime; and
- The genetic characteristics of the particular planting material.

The theoretical maximum yield is only obtained when the optimal value for *L* is achieved and maintained over the entire planted area for the duration of the planting cycle. Leaf area index is thus adversely affected when:

- the palm stand contains many missing palms (due to e.g. *Ganoderma),* leaning palms (e.g. due to poor land preparation in peat soils) or off-types, or where palms are planted at a suboptimal density, and
- the leaf surface is reduced by pruning, limited by poor nutrition or other growth factors, or damaged by pests and diseases.

In new plantings, economic returns are strongly related to the rate of canopy development. The optimal value for L should be reached as rapidly as possible and maintained throughout the life-span of the planting. The area of individual fronds con tinues to increase until about 10-12 years after planting (YAP) and is strongly influenced by the planting material (Hardon *et al., 1969;*

Gerritsma and Soebagyo, 1999 (Figure 1). Due to the increase in frond area with increasing palm age, optimal planting density is inversely related to age (Corley, 1973).

The value for *L* is a function of the number of fronds, the frond area and the palm density:

L = frond area (m^2) x frond number x palm density (palms ha^{-1}) / 10,000

In a field of palms planted on a red-yellow podzolic soil derived from volcanic material (ten-year mean rainfall 1,663 mm) *L* reached its maximum value about 8 YAP (Figure 1). The rate of frond opening decreases rapidly during the first 8 YAP but it must be remembered that the total number of green fronds on each palm is related to both frond opening rate and the rate of removal. Thus there is a steady decrease in frond number over time. Leaf area index decreased from 8 YAP planting due to a decrease in the frond number and a reduced rate of increase in frond· area (Figure 1).

Gerritsma and Soebagyo (1999) showed that frond area could be calculated reliably from measured values of petiole cross-section (PCS) during the first 6 YAP. Thus, a useful estimate of changes in *L* up to canopy closure can be calculated from measured values of PCS, the number of green fronds per palm and the tree stand (palms ha^{-1}). Since all these parameters are rather easy to measure in the field, it should be possible to monitor *L* on a field-by-field basis, at least up to canopy closure.

Canopy closure has been defined as the stage at which 80% of incoming radiation is intercepted by the crop (Breure, this volume) or when the fronds of three neighbouring palms overlap (Gerritsma and Soebagyo, 1999). The canopy is effectively closed well before fronds reach their maximum size. For standard palm densities of between 136-143 palms ha-1 this occurs at about 5 YAP but the precise timing depends also on factors such as soil fertility, fertilizer practices, climate and type of planting material (progeny or ideotype). Canopy closure occurs more rapidly with higher planting densities. In a density experiment in North Sumatra, canopy closure was reached ten months earlier with palms planted at 160 palms 'ha-1 compared with palms planted at 128 palms ha-1 (Gerritsma and Soebagyo, 1999). After canopy closure the number of fronds per palm required to attain the optimal L will decline as the average frond size increases (Table 1). For medium density plantings optimal L stabilizes at around 30 to 40 fronds palm-1 (equivalent to about 4-5 complete spirals of leaves) when leaves have reached maximum size about 10-12 YAP.

Successful canopy management implies that for any given site and age of palms the optimal number of leaves is retained. Too few leaves (i.e. suboptimal L) may result in a waste of solar radiation and reduced yield whilst an excessive number of leaves may result in greater inter-palm competition for light, larger respiration losses relative to photosynthetic gains, and increased vegetative and incremental growth at the expense of yield (Breure, this volume).

Unfortunate1y, all factors that lead to rapid and early canopy expansion and thus the early achievement of an optimal value for *L* and large yields in the first few years of harvest may, thereafter, lead to a further expansion of the canopy beyond optimal requirements and result in excessive inter-palm competition for light and reduced yields.

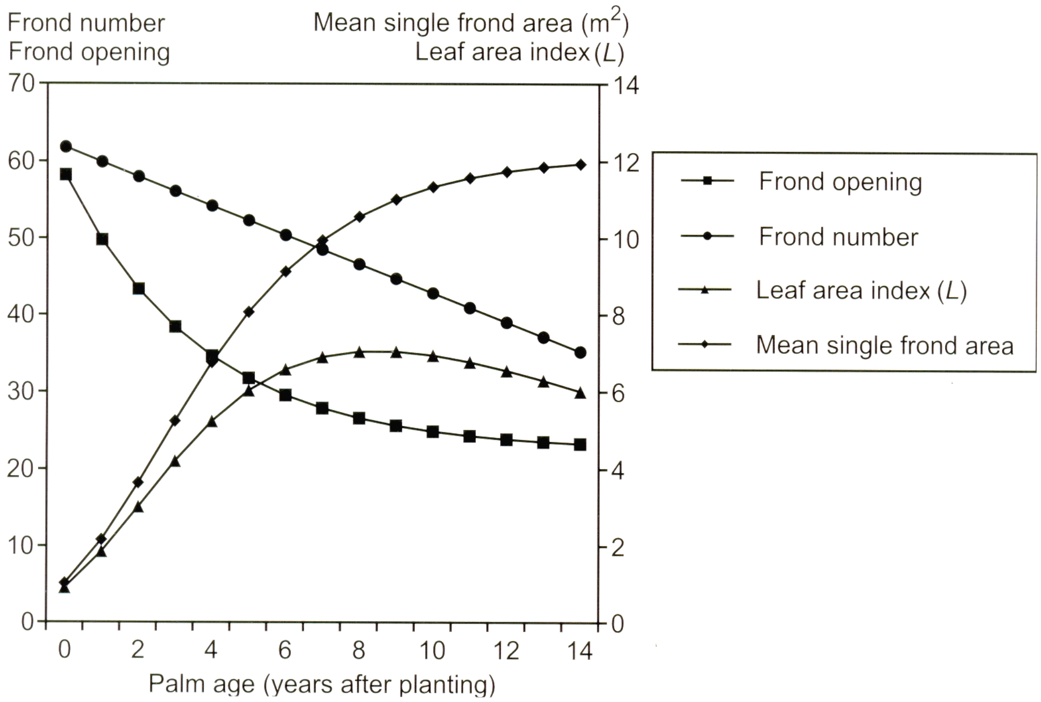


Figure 1. Relationship between frond area, annual frond opening rate, frond number per palm, leaf area index (L) and palm age for palms planted at 143 palms ha^{-1} on a red-yellow podzolic soil derived from volcanic material in North Sumatra (ten-year mean rainfall 1,663 mm yr^{-1}) (based on data and functions described in Gerritsma and Soebagyo, 1999).

There are two approaches to optimizing *L* through the life-span of a planting:

- A high planting density may be selected in order to maximize early yield, with a plan to remove a proportion of palms when inter-palm competition becomes excessive after canopy closure;
- A lower planting density (with corres ponding lower early yields) is selected so that the likelihood of inter-palm competition after canopy closure is minimized and the need for thinning is avoided.

In any event it requires skilled management to control and manipulate canopy development such that an optimal value for *L* is maintained throughout the lifetime of the planting. In agronomic terms this translates into the ability to maximize the exploitable yield potential of palms (Ooi et al. 1989).

The optimal value for *L* is related to site specific *soil* and climate characteristics, and thus, access to meteorological data and the results of soil testing and soil surveys is required to determine the optimal density for a particular site (Paramanantham, this volume).

CLIMATIC FACTORS AFFECTING THE OPTIMUM LEAF AREA INDEX (L)

I Solar radiation

Solar radiation is probably the most important factor that determines the optimum *L* for any given site. The greater the amount of solar radiation, the larger the optimum value for *L,* but persistent cloud cover and natural shade will reduce the optimum *L.* In practical terms this means that higher planting densities can be used in areas with more solar radiation, while lower densities must be considered in high rainfall areas where cloud cover is heavy and persistent (Table 2). Data on solar radiation is thus invaluable when selecting a suitable planting density. High planting densities may be feasible in high rainfall areas, however, where rainfall occurs in the late afternoon or evening. Such conditions are found in the foothills of Mount Ophir, West Sumatra, Indonesia where yield potential is very large due to a combination of high solar radiation, .high rainfall (but low cloud cover) and deep, well structured volcanic soils.

II Moisture regime

High solar radiation is sometimes associated with insufficient rainfall and soil moisture deficits. While intensive solar radiation favors a high value for *L,* moisture deficits act as a modifier that reduces the optimum value for *L* (Table 2).

Because of the effect of cloud cover in high rainfall areas on solar radiation, low solar radiation is unlikely to occur where soil moisture deficits are common except, perhaps, on very coarse textured soils.

Table 1. Approximate number of leaves required to achieve a given L at different planting densities and mean frond areas. The relation between leaf area and palm age is based on data of Gerritsma and Soebagyo (1999).

Approximate years after planting	Leaf area	Planting density (palms ha^{-1})								
		136			143			160		
		Number of fronds per palm								
	m^2	*L*=5	*L*=6	*L*=7	*L*=5	*L*=6	*L*=7	*L*=5	*L*=6	*L*=7
5	7	53	63	74	50	60	70	45	54	63
6	9	41	49	57	39	47	54	35	42	49
8	10	37	44	51	35	42	49	31	38	44
10	11	33	40	47	32	38	45	28	34	40
12	12	31	37	43	29	35	41	26	31	36

The regulation of *L* by canopy management is thus particularly difficult in regions with pronounced wet and dry seasons, and a smaller yield potential must be accepted in areas where the 'optimal' *L* is less than the capacity of the canopy to maximize net assimilation based on available solar radiation.

III High temperatures

High temperatures result in increased respiration losses and thus represent another modifier for the optimum value for *L*. A dense canopy (i.e. high value for *L*), may lead to lower within-canopy temperatures and this could minimize respiration losses.

SOIL FACTORS AFFECTING CANOPY DEVELOPMENT

Soil factors have a very strong influence on palm growth rate and on frond length. Deep, well-structured volcanic soils, for *example,* favor vigorous early growth and the production of very long fronds. Under such conditions, *early* yields can be very large, but inter-palm competition may become very pronounced soon after the onset of production. For example, there have been instances where bunch yields exceeded 32 t ha^{-1} at 3 YAP but yields subsequently decreased to <16 t ha^{-1} at 4 YAP. This may have been due to the early onset of inter-palm competition, the effect of excessive frond removal during the first year of production or to a negative feedback effect of the initial heavy bunch load (Jones, 1997).

By contrast, canopy expansion on deep peat soils and on sandy soils is usually slow, and density problems are uncommon even where the planting density is as high or greater than 160 palms ha-1 (Gurmit Singh et al., 1987; Mohd. Tayeb et al, 2002).

Table 2. Effect of solar radiation and soil moisture regime on optimal leaf area index (L).

Solar radiation	Soil moisture deficit	
	Common	Rare
Low	Higher *L*	Lower *L*
High	Lower *L*	Higher *L*

MANAGEMENT FACTORS AFFECTING CANOPY DEVELOPMENT

I Type* of *planting material

Different oil palm progenies vary greatly in terms of the pattern of canopy expansion. A smaller planting density should be selected for compact palm types with shorter fronds, whilst wider palm spacing is required for large palm types with longer fronds. For sites with a very favorable agro-climatic environment for oil palm (Paramanantham, this volume), suitable planting material provides for rapid crown expansion combined with a shorter time to full frond expansion (Breure, 1985).

1I Spacing

The optimal planting density may be defined as the density that yields the greatest discounted cash flow over a given period (Corley, 1977). No other factor affects canopy development as strongly as the plant spacing. Therefore, the selection of a suitable planting density, after taking into consideration soil and climate conditions and the type of planting material to be used, is a key management decision. Oil palm plant spacing ranges from 118-158 palms ha^{-1}, but initial populations of 136-143 palms ha^{-1} are the most widely used (Table 3).

Table 3. Density, inter-row space and optimal leaf area for common planting distances used in oil palm.

Density (palm ha^{-1})	Distance along rows (m)	Distance between rows (m)	Corresponding optimal frond area (m^2) at > 10 YAP*
158	8.5	7.4	9.1
148	8.8	7.6	9.8
138	9.1	7.9	10.8
129	9.5	8.2	12.0
121	9.8	8.5	13.5

** Calculated using the equation of Corley (1973).*

A lower palm density is usually preferred where soil conditions are more favorable. Higher planting densities are used where solar radiation is very high and soil moisture deficits are uncommon, but a lower planting density is selected where the amount of solar radiation is reduced by climatic conditions.

Planting density, palm spacing and inter row spacing are interdependent variables that can be derived from the following equations:

Palm density (palm ha^{-1})
= 10,000/(palm spacing [m] x 0.866)

Plant spacing (m) = './10,000 /(palm density [palms ha^{-1}] x 0.866)

Inter-row spacing (m)
= Palm spacing x 0.866

Corley *et al.* (1973) developed the following equation to assess the optimal palm density according to the mean frond area in mature palms >10 YAP:

Optimal density (palms ha^{-1})
= 91 + (5,500/mean frond area [m^2])2

For more detailed information on the selection of suitable planting density in oil palm the reader is referred to Chemara Advisory Service (1969), Corley (1976), Corley (1977), Corley *et al.* (1973), Donough and Kwan (1991), and Tan and Ng (1977).

Experienced planters recognize the importance of early yield to generate cash flow, particularly in new development projects, even though this may necessitate thinning after canopy closure to prevent inter-palm com petition and premature yield decline in later years. If the necessary thinning is delayed, the gains in terms of early yield may be offset by a rapid yield decline in later years.

It should also be remembered that the increased returns from large early yields are partly offset by the greater establishment, maintenance and thinning costs for high density plantings, and the possible loss of yield if thinning is delayed (Hartley, 1988).

The selection of a suitable planting density is only the first step in canopy management. The planter must then make sure that lining and planting are carried out accurately in the field such that each palm has equal access to light, water and nutrients (Gillbanks, this volume). The objective during plantation establishment, therefore, is to achieve a grid of planting points across the entire planted area according to the prescribed planting distance. Roads are then fitted to the palm grid.

It should be remembered that small errors in marking out planting points translate into large errors in planting density. For example, an error of ±0.5 m in the palm spacing for a planned density of 136 palms ha^{-1} results in a final density of 122 or 152 palms ha-' (Figure 2).

Uneven palm stands are often found on steeply sloping land where the distance between palms was measured along the slope and not by horizontal distance. Thus, palms are spaced too close together resulting in inter palm competition in later years. It is quite common to find strong inter-palm competition in steeply sloping areas for this reason. When lining sloping land for planting, the horizontal space between palms should be maintained by taking account of the slope.

III Pruning

Pruning is a very sensitive means to adjust the palm canopy and *L.* A review of oil palm pruning and the relationship between frond area and yield is given by Henson (2002). Pruning is carried out with one or more of the following objectives:

- To provide access to ripe bunches at harvest;
- To remove old fronds retained at harvest that do not subtend a bunch;
- To reduce the loss of loose fruits trapped in frond axils;
- To reduce the growth of epiphytes;
- To remove dead, damaged or diseased fronds and thus increase the rate of palm recovery after pest and disease incidence;
- To optimize canopy conditions by reducing inter-palm competition.

Several trials in Malaysia have shown that excessive frond removal reduces yield (Hartley, 1988). Moderate pruning reduced yield in palms planted on a coastal clay soil in Malaysia and the greatest effect occurred when the frond number was reduced to <40 $palm^{-1}$ (Figure 3a). In another experiment, with palms 8-12 YAP on less fertile inland soils, yields were reduced significantly when the frond number was reduced to <32 $palm^{-1}$ by repeated pruning at six-week intervals (Figure 3b).

Temporary excessive pruning has an immediate and short-term effect on bunch weight. Prolonged excessive pruning reduces both bunch weight and bunch number (after a time lag of 10-12 months) and has a correspondingly greater overall effect on yield. The rate of recovery from a temporary period of excessive pruning is more rapid in young palms because of their greater frond production rate (see Figure 1).

How many fronds should be retained on each palm? The number of fronds required to achieve different values for *L* at a particular planting density can be calculated from the relationship between frond area and age (Gerritsma and Soebagyo, 1999) (see Table 1). In young palms, where fronds do not yet overlap, and where the *L* has not yet reached the optimum value, all green fronds should be retained. This requires close supervision of weeding operations during the period up to maturity, because workers are always tempted to remove parts of fronds or even whole fronds from young palms to make circle weeding easier. Thus, pruning should not start before palms are ready for sanitation pruning, prior to scout harvesting. Under favorable soil and climate conditions and with good field management, young palms should come into production at 24-30 months after field planting.

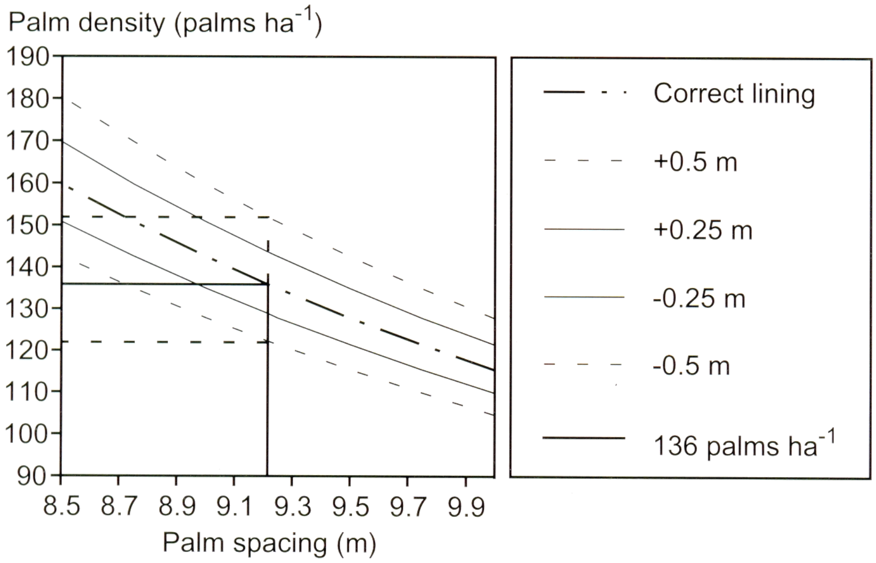


Figure 2. Effect of errors in palm spacing on planting density. Where the planned density is 136 palms ha^{-1} an error of ±0.5 m in palm spacing alters the final density to 122 or 152 palms ha^{-1}.

In young mature palms «8 YAP), two fronds should be retained beneath the lowest positioned bunch on the palm. In older mature palms (>8 YAP), a single frond subtending the' lowest positioned bunch should be retained with the aim of maintaining the required *L* (see Table 1). Two rounds of pruning may be required each year to prevent the accumulation of dead fronds that hang from the crown and interfere with harvesting. About 40 fronds palm-^{1} should generally be retained in older palms (>10 YAP).

IV Pests and diseases

Wood *et al.* (1973) showed that pruning young fronds in the upper part of the crown resulted in greater yield losses than removal of older fronds. Thus, the decrease in yield will be greatest where pests or diseases affect the upper part of the palm canopy. Timely intervention to control pests and diseases before the canopy is damaged is therefore a very important aspect of canopy management.

V Leaf nutrient status

In an experiment to measure the effect of pruning on leaf nutrient status, Yeow et al. (1982) found that frond nitrogen (N) and potassium (K) status were increased but leaf magnesium (Mg) status was reduced when frond removal was greatest (Figure 4). The practical implication of this work is that apparent leaf N and K status will be greater and Mg status reduced in field palms that are over-pruned prior to leaf sampling. This may lead to an over- or underestimate of palm nutritional status depending on frond removal.

The removal of female flowers in young palms for a limited period during the immature growth phase, termed ablation, results in increased vegetative growth because CH2O is spared from use for generative growth resulting in an increased rate of frond production, increased frond length and weight, and greater palm girth (IRHO, 1976). Female inflorescences should be pulled from frond axils as soon as they are visible in 50% of the palm stand. In well managed new developments, ablation can be practiced during the period from 12 to 18 months after planting assuming palms are brought into production at 24 months. It is sometimes argued that ablation is not feasible where labor is in short supply but the labor requirement for this operation is, in fact, very small (2-3 operations requiring about 0.2 man days ha·1).

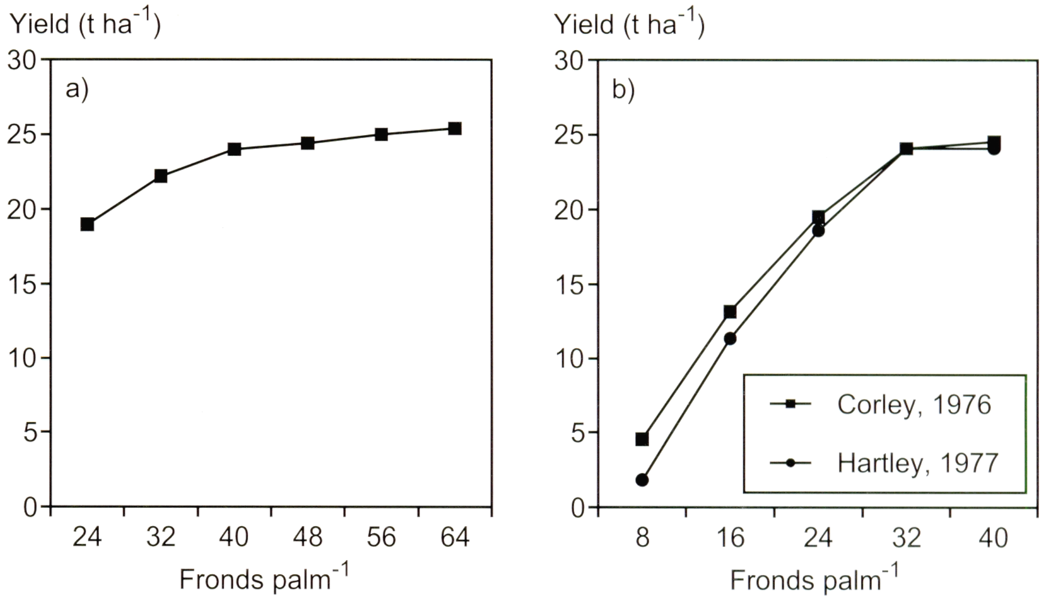


Figure 3. Relationship between fruit bunch yield and frond number in palms planted on coastal soils (Hartley, 1988) (a); and inland soils with mean data over four years from Corley (1976) and two-year means from Hartley (1988) (b).

VII Fertilizer

In almost all environments fertilizer has a large effect on palm growth and canopy development. Among the major nutrients, N and K have the strongest effect on palm growth rate and frond area. Palms planted on low soil phosphorus (P) status soils, however, will show a pronounced pyramid shape and produce small fronds if soil P deficiency is not corrected. Large and frequent applications of N fertilizer increase the rate of frond expansion and early yield but too much fertilizer N can result in excessive canopy growth, leading to severe inter-palm competition for light, decreased yield and excessive growth in height.

Breure (1977) found that the yield response to fertilizer was related to the amount of inter palm competition. In a fertilizer experiment with three planting densities on volcanic soils in West New Britain, Papua New Guinea, yield response to fertilizer was large where the density was 110 palms ha-^{1}, but there was no response at 186 palms ha-^{1} due to inter-palm competition.

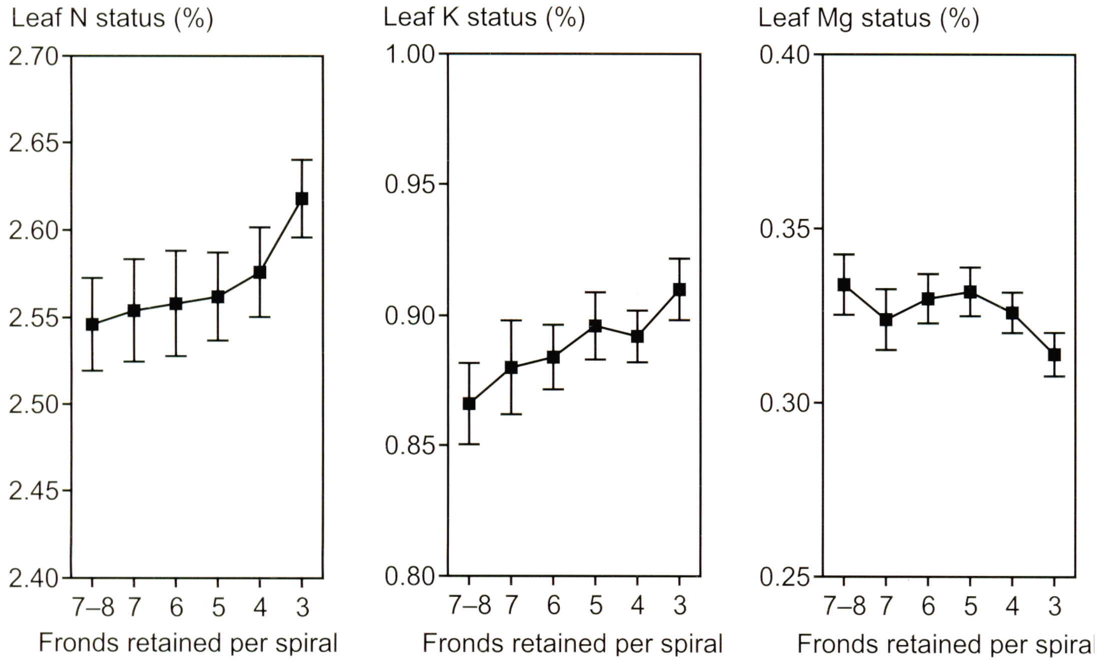


Figure 4. Effect of pruning on leaf N, K and Mg status in frond #17 (Yeow et al., 1982). Bars represent standard errors of means.

VIII Harvesting

Careless harvesting can result in unwanted frond depletion, particularly in young palms. To maintain optimal canopy conditions in young palms it is essential to minimize frond removal and this can only be achieved if ripe bunches are removed without cutting the subtending frond. Harvesters should be equipped with chisels with a narrow blade (:56 cm) for this purpose.

It is important to remember that excessive frond removal affects the highest yielding palms most. Young, high-yielding palms in the process of producing a large yield of bunches (up to 30 bunches palm-[1] yr-') are under considerable physiological stress. If frond removal is excessive the resultant stress may force affected palms to enter an unproductive period due to the effect of stress on floral initiation, sex determination and floral abortion (Breure, this volume). Even thereafter, such palms may exhibit a cyclic pattern of production with alternating periods of high and low productivity for a considerable period of time.

In older palms harvesting is almost invariably accompanied by frond removal due to the practical difficulty of removing bunches in the presence of the subtending and closely adjacent fronds. Henson and Chai (1998) noted seasonal variations in L that were inversely related to changes in harvest bunch numbers, indicating the impact that seasonal peaks in harvesting may have on L (Figure 5).

The effect of frond removal during harvest becomes less critical, however, in older palms where high yield is related more to bunch weight than the number of bunches per palm. Thus, a single frond retained beneath the oldest bunch or a total canopy of 40 fronds is sufficient in palms >8 YAP.

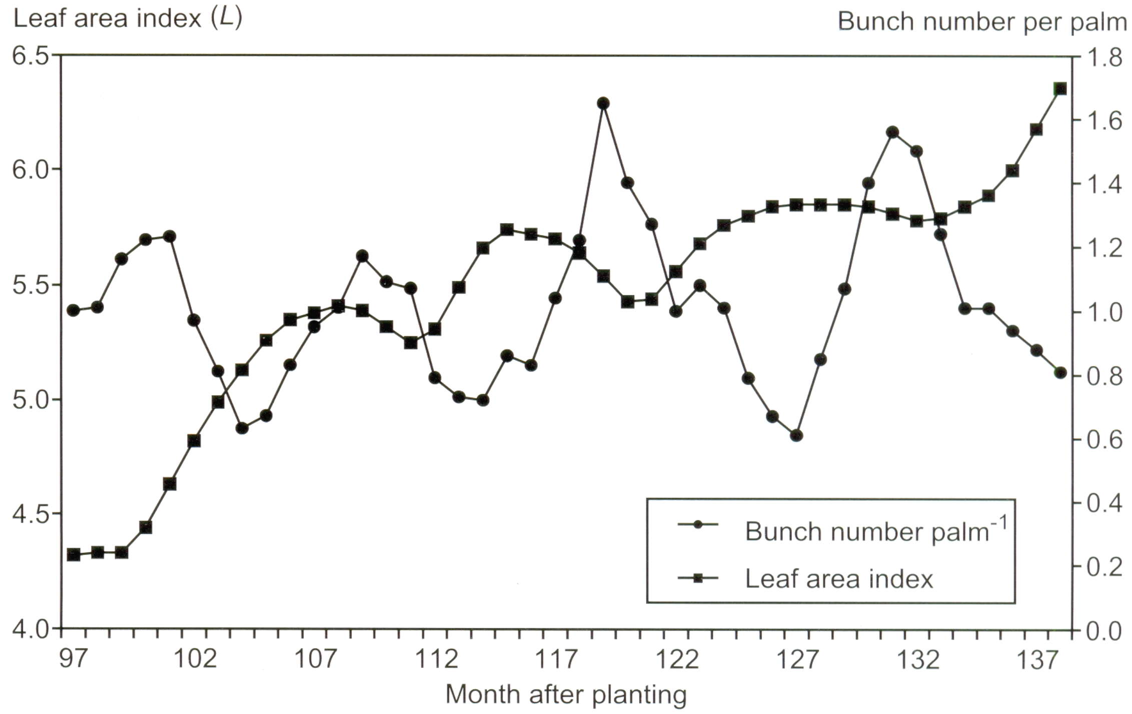


Figure 5. Changes in leaf area index L in relation to bunch harvest in a commercial field (94 ha) in Malaysia (adapted from Henson and Chai, 1998).

THINING

Thinning remains a rather controversial issue in oil palm management mainly due to the dearth of experimental evidence on the effect of different thinning methods on yield over the long term. It may be carried out under two different circumstances:

- On an *ad hoc* basis if there are indications that yield is declining due to excessive inter palm competition;
- As part of a planned strategy to optimize palm density over the life of the planting.

By 8-9 YAP, frond area may have already increased such that there is considerable inter palm competition due to mutual palm shading within the canopy. Under such conditions, assimilates are preferentially allocated to vegetative growth (Corley *et al.,* 1971; Squire, 1984) resulting in a decrease in bunch number (due to increased floral abortion and reduced sex ratio) and bunch weight.

Strong inter-palm competition results in reduced yield, increased rates of trunk vertical growth and frond etiolation (Ooi *et al., 1989).* In addition, inter-palm competition makes harvesting more difficult due to the taller stand, and may result in increased soil erosion due to the disappearance of ground vegetation when light penetration through the canopy is reduced.

How can inter-palm competition be assessed and what are the symptoms? As shown above, Corley *et al.* (1973) derived a useful formula to estimate whether a particular planting density is optimal in mature palm stands >1 0 YAP based on an estimate of the mean frond area. Various indicators of inter palm competition were summarized by Turner and Gillbanks (1974) and reviewed by Corley (1977) (Table 4).

Early experiments on the effect of thinning palm stands where inter-palm *competition* was *evident* or suspected produced inconclusive results (Corley *et al.,* 1973). However, thinning can be an effective means to prevent a rapid yield decline wherever palms are planted at high densities or in environments with soil and climate conditions that favor excessive vegetative growth (Menendez, 1988, Nazeeb *et al., 1990).*

Ooi *et al.* (1989) measured the effect of systematic hexagonal thinning (i.e. 1 palm in 7 removed or 14% of the palm stand) in palms planted on soils derived from granite on the east coast of Peninsular Malaysia and flat alluvial soils in Sabah (Figure 6). Yield was increased when the palm stand was reduced, even at very low planting densities (110 palms ha-1) (Figure 6a), and a precipitous yield decline was arrested in Sabah by thinning palms at 11 YAP (Figure 6b). Yields continued to decrease during the first year after thinning but subsequently recovered strongly, particularly in the more fertile alluvial soils in Sabah. Similar effects of this thinning strategy have been reported for oil palm stands in eastern Colombia (Bastidas *et al., 2000).*

Systematic thinning results in the most uniform field geometry but does not change the composition of the palm population. To produce a yield of, say, 34 t ha-1 fruit bunches from a stand of 136 palms ha-1 the average yield per palm must be 250 kg but there may be many palms yielding >300 kg bunches palm-1 and others at the lower end of the scale producing <100 kg bunches palm-1.

In spite of rigorous culling before planting, all adult populations of dura-pisifera (D x P) material are somewhat heterogeneous with a mixture of some very high yielding palms and others that may yield very little during the life span of a planting. Measurements carried out in commercial fields showed that variation in individual palm yield was present irrespective of the yield capacity of the site (Henson, unpublished results) (Figure 7). The higher mean yield of the wetter field simply skewed the distribution to the right.

Systematic thinning results in the *removal* of palms from each yield category, and palms yielding 300-400 kg bunches palm-1 may be removed whilst palms yielding very little are retained. Thus, with systematic thinning, any increase in yield is derived solely from reducing inter-palm competition.

An alternative approach is to carry out *selective* thinning and remove palms that have been found to produce small yields. In this way, there is potential to increase yield by reducing inter-palm competition and changing the composition of the stand to a higher yielding population.

Selective thinning should follow a very carefully implemented step-wise approach, however, in which candidates for removal are selected during palm census and monitored for a period of 6-12 months before identifying palms that should be poisoned and removed.

The target of a successful thinning operation must be to remove the 14% lowest yielding palms in each field.

It is also prudent to measure the effect of thinning in some closely monitored trial areas before thinning large areas of an estate. Remote sensing, using high-resolution IKONOSTM images, may provide useful and practical techniques to analyze canopy characteristics in oil palm in the future (Fairhurst *et al.,* this volume; Liew, 2001).

Table 4. Indicators of inter-palm competition in oil palm (modified from Turner and Gillbanks, 1974 and Corley, 1977).

Indicators of inter-palm competition	Comments
Quantifiable	
Reduced light intensity in the field.	Must be measured carefully due to presence of 'sun-fleck' areas beneath the canopy.
Larger yields and smaller incremental growth in roadside palms.	Possible to compare yield and height increment in core field palms with border palms in selected fields where competition is suspected and not suspected.
Reduced yield.	Difficult to separate normal fluctuations in yield from the effect of inter-palm competition. Proper yield recording and analysis essential.
Trunk etiolation.	An increase in density of 25 palms ha^{-1} results in a change in incremental growth of a total of 0.3 m over 20 years.
Increased rachis length.	Detectable before any changes in trunk height.
Qualitative	
Sparse ground vegetation due to reduced light penetration.	Subjective criterion to be used with caution.
Interlocking and overlapping fronds.	Subjective criterion to be used with caution.
Erect frond appearance. Deformed bunches due to the effect of pressure from subtending fronds on bunches during formation.	Subjective criterion to be used with caution.
Deformed bunches due to the effect of pressure from subtending fronds on bunches during formation.	Subjective criterion to be used with caution.
Premature death of lower fronds.	May also be caused by potassium (K) deficiency.

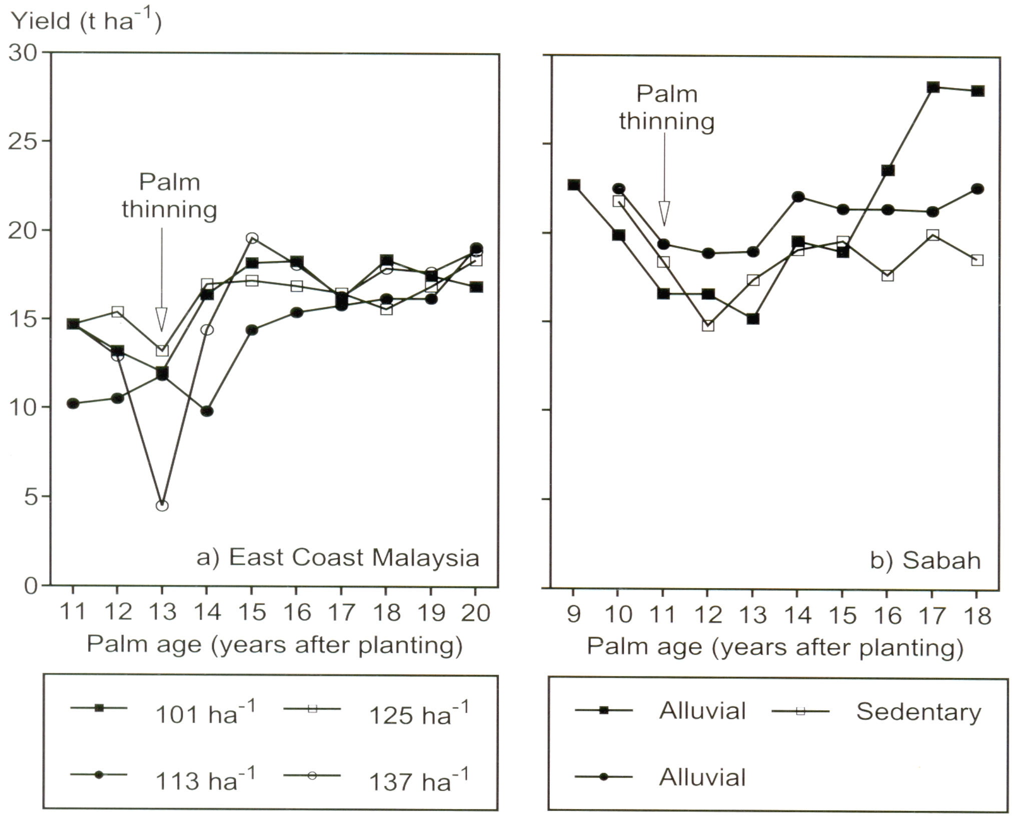


Figure 6. Effect of thinning on bunch yield in inland soils in East Malaysia and Sabah (Ooi et al., 1989; Ng et al., 1990).

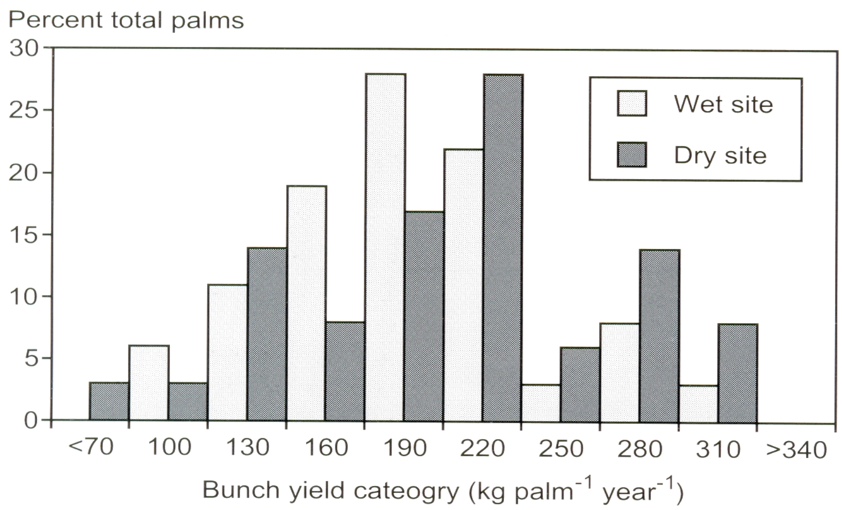


Figure 7. Examples of the variation in yield between individual palms in two commercial fields (referred to as dry and wet sites respectively) in Malaysia. Data are means over three years of harvesting from 9–11 YAP (Henson, I.E., unpublished results).

The procedure for thinning is as follows:

1. Inspect the field for symptoms of inter-palm competition (see Table 4).
2. Calculate the optimal density based on measured frond area using the formula of Corley (see above).
3. Mark all palms that occupy the center of each 'hexagon' in the field with a blue ring during a palm census operation (Figure 8)
4. Mark the three poorest performing palms in each group of seven palms (i.e. the center and six surrounding palms) with a red ring. The candidates for removal can be anyone of the seven palms that comprise the hexagon.
5. Repeat the palm census after six months.
   Select one of the three palms identified as poor performers for removal.

6. Poison all palms marked for thinning.

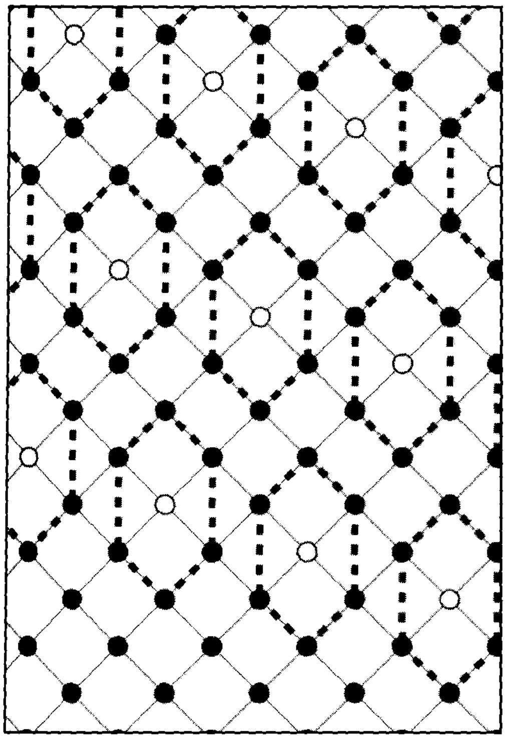


Figure 8. Location of palm groups in a hexagonal pattern. Central palms are shown with an open symbol. The least productive palm in each group of seven is removed to reduce the planting density by 14%.

This procedure results in the removal of the poorest yielding palms, reduces inter-palm competition and provides acceptable palm canopy geometry.

Candidate palms for removal in a selective thinning operation include the following:

- giant sterile pisifera palms,
- weak, small, and poorly developed palms,
- palms showing abnormal characteristics (e.g. genetic orange spotting, narrow leaf, orange-yellow petiole base, chimeras),
- very tall, leafy palms (such palms partition assimilates inefficiently and, for this reason, often have rapid incremental growth and compete most for light, water and nutrients while contributing little to yield), and
- supply palms that were shaded during early growth and have not developed properly.

Palm thinning also results in improved response to fertilizer, reduced labor for harvesting, and less pruning and weeding costs. Thinning also stimulates groundcover growth in the exposed areas, and such areas can be utilized temporarily; e.g. for growing nectar producing plants attractive to beneficial insects.

It is worth noting that yield and palm census records should be maintained for all fields for the life of each planting so that yield data (i.e. t ha^{-1} fruit bunches; kg bunches per productive palm) and changes in vegetative growth (measurements of PCS) can be monitored continuously and provide a quantitative basis for decisions on the need for thinning.

CANOPY MANAGEMENT AT REPLANTING

Replanting is carried out when palms become so tall that complete harvesting is not possible or when yields are so small that replacing the stand with high yielding palms will provide a better economic return (Hartley, 1988). Several workers have investigated the possibility of planting seedlings beneath the old canopy and subsequently pruning and then poisoning out the old palm stand in order to maintain some productivity through the replanting period (Chia *et al., 2002).*

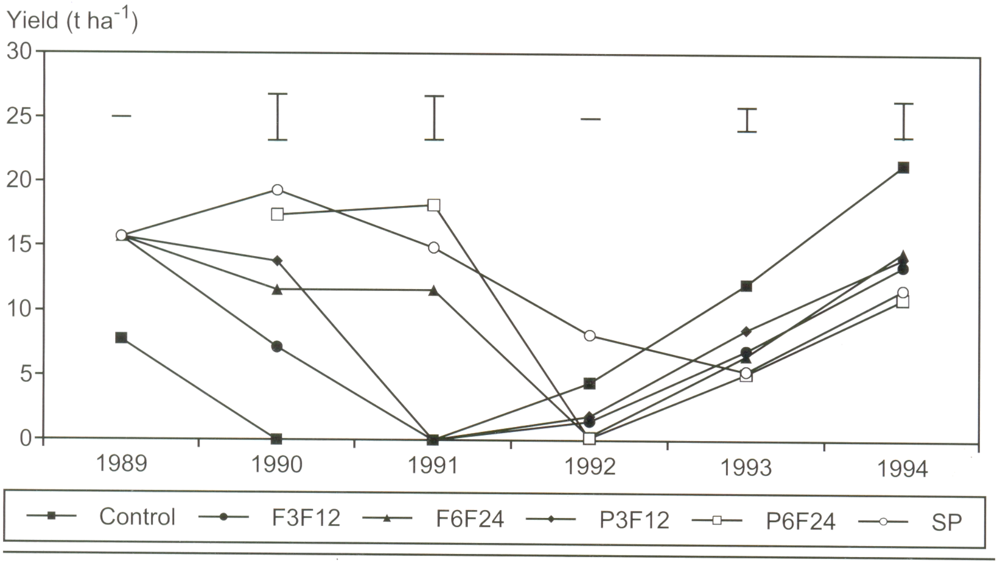
The argument made is that reduced growth and performance of the new stand, due to the shade provided by the old stand, is more than offset by the additional revenue stream from the old stand during the replanting period. Where *Ganoderma* has become endemic, however, (e.g. most of North Sumatra and Peninsular Malaysia), pathologists consider it prudent to clear fell the old stand.

In Thailand, where *Ganoderma* has not yet become a problem, under-planting has been shown to produce better economic returns but requires careful and timely implementation. Tittinutchanon and Corley (2002) compared five different combinations of pruning and partial felling in a replanting trial in Southern Thailand (Figure 9). Whilst yield was smaller in the new under-planted palms compared with the clear-felled control, the most profitable treatment, under a range of palm oil prices, was to fell half the old stand at six months after under-planting and the remainder at 24 months after replanting (Figure 9, treatment F6F24) Furthermore, the cumulative yield over the period recorded from replanting/under-planting to 12 YAP was significantly greater under F6F24 compared with the control (Figure 10).

CONCLUSION

In this chapter we have attempted to demonstrate the importance of correct management of the size of the oil palm canopy to achieve maximum economic yield. The various practices, which influence this, have been discussed and recommendations have been made regarding their correct implementation.

It is considered that the additional effort in doing so should be more than amply repaid through increased productivity.



Treatment	Details
Control	Clear-felling at replanting.
F3F12	50% palm removal at 3 months and 50% at 12 months after replanting.
F6F24	50% palm removal at 6 months and 50% at 24 months after replanting.
P3F12	Removal of distal half of 16 oldest fronds at 3 month intervals starting 3 months after undeplanting and clear felling at 12 months.
P6F24	Removal of distal half of 16 oldest fronds at 3 month intervals starting 6 months after undeplanting and clear felling at 24 months.
SP	50% old stand pruned to 8 fronds palm^{-1} at 6 months, pruning repeated at 3-month intervals and felled at 24 months. 50% pruned to 8 fronds palm^{-1} at 24 months repeated at 3-month intervals and felled at 33 months.

Figure 9. Yield of fruit bunches in six replanting practices in a replanting experiment in Southern Thailand (Tittinutchanon and Corley, 2002). Bars represent LSD (P<0.05).

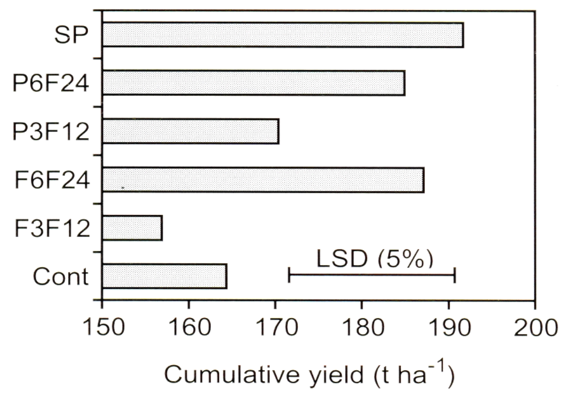


Figure 10. Cumulative yield (1989–2000) in a replanting experiment in Southern Thailand (Tittinutchanon and Corley, 2002). Treatments were as described for Figure 9.

Important points for practical planters

General

1. Select planting density after taking account of site conditions and planting material.

- Refer to meteorological records.
- Refer to results of soil surveys and soil testing.
- Consider experience of neighboring plantations.
- Establish a uniform grid of planting points so that each palm has equal access to soil, nutrients, water and light.

2 Plant only high quality seedlings obtained from a reputable seed producer.

- Remove off-types before planting.
- Remove remaining off-types in the first two years after planting and replace with healthy palms.

Leaf canopy

1) In young palms, the focus should be on frond management with careful selection of planting density, adequate N fertilizer use, and maximum frond retention to reach optimal leaf area index as rapidly as possible.

2) In mature palms, the focus should be on *canopy* management with finely tuned N applications, moderate pruning and selective thinning to maintain an optimal leaf area index throughout the adult life of the palm stand.

Pruning

1) Minimize frond removal to maintain canopy size, especially during the first 7 YAP.

2) From 8 YAP a single frond subtending the lowest bunch should be retained.

Thining

1) Between 3-6 YAP remove all remaining unproductive and diseased palms but only replace voids where there are two consecutive planting points.

2) Start thinning from 7 YAP onwards if there is clear evidence that yield decline can be related to inter-palm competition.

Where thinning is carried out, remove only the lowest yielding palms in each hexagon comprising seven palms.

Replanting

1) Replanting is carried out when palms become so tall that complete harvesting is no longer economic.
2) Consider under planting where the risk from Ganoderma is small and *Oryctes* beetles can be controlled.