VARIABLE DENSITY PLANTINGS FOR OIL PALMS (*Elaeis guineensis*) IN PENINSULAR MALAYSIA

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ABSTRACT

The current planting density is a fixed option based on the duration of the economic life cycle of the oil palm, which is about 25 years in Malaysia. As space requirement increases as palm grows bigger with age, the density giving greatest yield therefore decreases gradually from high to a lower stable density at some point in the planting cycle. This behaviour is premise for one of the key options investigated in this project, the concept of variable density (VD). In this option, palms are planted at high densities and thinned when the starting density is no longer the optimum density for the given period. Because of the morphology of the oil palm, planting patterns influence greatly the yields obtained both before and after thinning. The project investigated several of the key elements in the VD concept. They are the starting and finishing densities, planting patterns, thinning periods, intensity of thinning and manuring requirements (one of the high cost items affected by density). A second option investigated is the concept of fixed high density planting (HDP) on a shorter 18-20-year cycle. This allows a quicker introduction of newer varieties which yield better or with special traits (high iodine value, disease resistant, low height increment, etc.*) in successive replants with concomitant better profitability. This option is also suitable for land under acquisition threat or development potential. The strategies are evaluated over six experiments on both coastal and inland soils. Results to date suggest both strategies are viable and have potential. Results from the spacing experiments indicate that HDP, on a shorter replanting cycle is more economical. However, on conventional planting cycles of 25 years, current fixed planting densities are still valid. The results from the VD options suggest that initial starting densities at triangular spacing are better than other planting pattern despite the resultant spacing after thinning being asystematic. Starting densities at 180 – 200 palms ha^{-1} at triangular spacing and thinned at around the 12th – 14th year of planting by 14% – 25%, appears to be viable. Future research directions and experimental limitations are also discussed.*

Keywords: planting density, high density planting, variable density, thinning, oil palms.

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INTRODUCTION

The optimum density of planting oil palm is defined as the density giving the maximum cumulative profit or discounted cash flow over a given period or the economic life of the palm (Corley, 1977). Despite several studies to elucidate the optimum density (Prevot and Duchesne, 1955; Sly and Chapas, 1963; Corley *et al.*, 1973; Tan and Ng, 1977; Goh, 1982), the issue has yet to be satisfactorily resolved. The problem is complex because the optimum density at a given period varies with age, environment, genotypes, soil and management practices (Sly and Chapas, 1963; Corley *et al*., 1973; Breure, 1977; Maliphanti, 1978). In most cases, the optimum declines with age when interpalm competition becomes severe (Corley, 1977). As a result of all these factors and the absence of data on thinning responses to take advantage of the shifting optimum with age, the current commercial optimum is actually a fixed one, which is based on the best lifetime yield expectation for the given environment. The commercial planting density adopted in the major oil palm growing regions of the world ranges from 130 to 150 palms ha^{-1} (Hartley, 1977; Corley *et al*., 1973; Redshaw and Siggs, 1995).

There have been significant improvements in the planting materials in relation to those used in the past spacing experiments. These experiments also indicated significant progeny x density interactions (Corley, 1973; Maliphanti, 1978; Corley and Donough, 1992). Current materials have been intensively selected for bunch index (the ratio of fruit bunch dry matter to total dry matter production) and may thus be able to tolerate a much higher planting density.

Based on the review of numerous spacing experiments in both perennial tree crops and annuals, in general, and oil palms in particular, Nazeeb (2000) investigated a series of options to optimize the planting density of oil palm. This article presents an update of the project.

MATERIALS AND METHODS

Experiment 1: Spacing and Fertilizer Requirements for Palms on Inland Sedentary Soils

This experiment evaluates a range of density x manuring regimes on Rengam Series (*Typic paleudult*). It was planted in September 1981 at CEP Rengam Estate, Rengam, Johor, using an adaptation of Nedler's Systematic Design 1a (Goh, 1977). The experiment consists of one full and two half circles representing four replicates. The details of the experiment are as follows:

Density range: 225 to 41 palms ha^{-1}, in 18 steps. The innermost two and the outermost two densities are guards, thus, the actual density range under evaluation is 184 to 50.
$\theta = 5^o$ (angle between spokes)
$\alpha = 1.0516$ (spacing constant)
$\tau = \sqrt{3}$ (rectangularity)
Terrain = gently undulating (2^o– 6^o) to steep (6^o– 12^o)

Three rates of manuring were tested with the densities viz. half normal estate rate (F1), normal estate rate – F2 (3 kg AS + 3 kg MOP + 1 kg RP + 2 kg kieserite palm^{-1} yr^{-1}) and twice normal estate rate (F3).

The FFB yield data was fitted to the Holiday equation, which Goh (1982) and Iyer *et al*. (1985) showed to give the best fit for data from the systematic fan design.

Bunch analysis was carried out during 1991 and 1994 when the palms were 10 and 13 years old respectively. At each sampling, six bunches per plot (per density per fertilizer) were analysed.

Experiment 2: Spacing and Fertilizer Requirements for Palms on Coastal Alluvial Soils

This experiment evaluates a range of density x manuring regimes on Bernam Series (*Typic tropaquept*). It was planted in December 1988 at Sungai Buloh Estate, Bukit Rotan, Selangor. It is a systematic design with two replications laid out as a full circle (Nelder, 1962; Goh, 1977) with densities ranging from 332 – 81 palms ha^{-1} in 16 steps.

All palms were mulched with empty fruit bunch (EFB) during immature phase. Two rounds of circle mulching, at planting and 12 months later, were carried out. Each palms was mulched with 185 kg of EFB and a supplementary application of 250 g RP and 700 g urea per round. Manuring treatments were only introduced upon maturity, in September 1991. Manuring treatments at maturity were as follows:

1. Normal estate rate applied on a per palm basis (F1).
2. Normal estate rate applied on a per unit basis (F2).
3. 2 x normal estate rate applied on a per unit area basis (F3).

The normal estate rate on unit area basis is based on the rate for 136 palms ha^{-1} @ 272 kg urea, 408 kg MOP, 204 kg RP and 136 kg kieserite. The normal estate rate on a per palm basis is 2 kg urea, 3 kg MOP, 1.5 kg RP and 1 kg kieserite yr^{-1}.

Experiment 3: Variable Density Option on Coastal Soil Using Triangular Spacing

This experiment determines the economic optimum density, by starting out at a high density triangular planting and later thinning to non-triangular spacing, for oil palms on Bernam Series (*Typic tropaquept*). It was planted in December 1988 at Sungai Buloh Estate, Bukit Rotan, Selangor. It was laid out as a half circle using the systematic design (Nelder, 1962; Goh, 1977), with densities ranging from 362 – 64 palms ha^{-1} in 19 steps.

All palms were mulched with EFB during the immature phase. Two rounds of circle mulching, at planting and 12 months later, were carried out. Each palm was mulched with 185 kg of EFB and a supplementary application of 250 g RP and 700 g urea round^{-1}. Upon maturity, palms were fertilized on a per palm basis at 2 kg urea, 3 kg MOP, 1.5 kg RP and 1 kg kieserite palm^{-1} yr^{-1}.

Systematic thinning at 14% was carried out in one quadrant in July 1997. Two quadrants were left as unthinned control.

Experiment 4: Variable Density Option on Coastal Soil Using Square Spacing

This experiment determines the economic optimum density, by starting out at a high density square planting and later thinning, maintaining the square spacing, for oil palms on Bernam Series (*Typic tropaquept*). It was planted in December 1988 at Sungai Buloh Estate, Bukit Rotan, Selangor. It was laid out as a half circle using the systematic design (Nelder, 1962; Goh, 1977), with densities ranging from 394 – 60 palms ha^{-1} in 13 steps.

All palms were mulched with EFB during the immature phase. Two rounds of circle mulching, at planting and 12 months later, were carried out. Each palm was mulched with 185 kg of EFB and a supplementary application of 250 g RP and 700 g urea round^{-1}. Upon maturity, palms were fertilized on a per palm basis at 2 kg urea, 3 kg MOP, 1.5 kg RP and 1 kg kieserite palm^{-1} yr^{-1}.

Systematic thinning at 25% was carried out in one quadrant in July 1997. Two quadrants were left as unthinned control. Square pattern allows a two stage systematic thinning and finished up as a systematic planting. The experiment is not yet due for the second stage thinning.

Experiment 5: Variable Density Option on Inland Sedentary Soil Using Hexagonal Spacing

This experiment determines the economic optimum density, by planting at double densities in a hexagonal pattern and thinning by half to a systematic spacing for oil palms on Rengam Series (*Typic paleudult*). It was planted in April 1987 at Selatan Baru Estate, Merlimau, Melaka. It was laid out as a full circle using the systematic design with four quadrants (Nelder, 1962; Goh, 1977), with densities ranging from 360 – 100 palms ha^{-1} in 14 steps. The double density at hexagonal spacing was achieved by superimposing an identical circle at an offset of 1.7^{o} from the radii of the first circle. Details of the laid out are illustrated by Nazeeb *et al.* (1990).

Palms were fertilized on a per palm basis at normal estate rates, viz. 3.75 kg AS, 2 kg RP, 3.75 kg MOP and 2 kg kieserite palm^{-1} yr^{-1}.

The first quadrant was thinned in November 1994, the second in May 1996 and the third in January 2003. Thinning was by 50% and was achieved by removing complete radii from the offset circle leaving an equilateral triangular spacing at half the density.

Experiment 6: Optimizing Variable Density Options on Coastal Soil

This experiment evaluates the potential of variable density planting, by planting in conventional blocks with 12 months old seedlings in December 1992 at Jalan Acob Estate, Kapar, Selangor on Jawa Series (*Typic sulaquept*). The experiment was laid out as a split plot design with two replications. Thinning is a nested factor within density. Treatments were factorialized between density, thinning intensities and thinning periods as below:

Density (palms ha^{-1})	Thinning intensity (%)	Thinning period
185	0 14	T1 (thinned in January 2003)
160	25 33	T2 (yet to carry out)
136	-	-

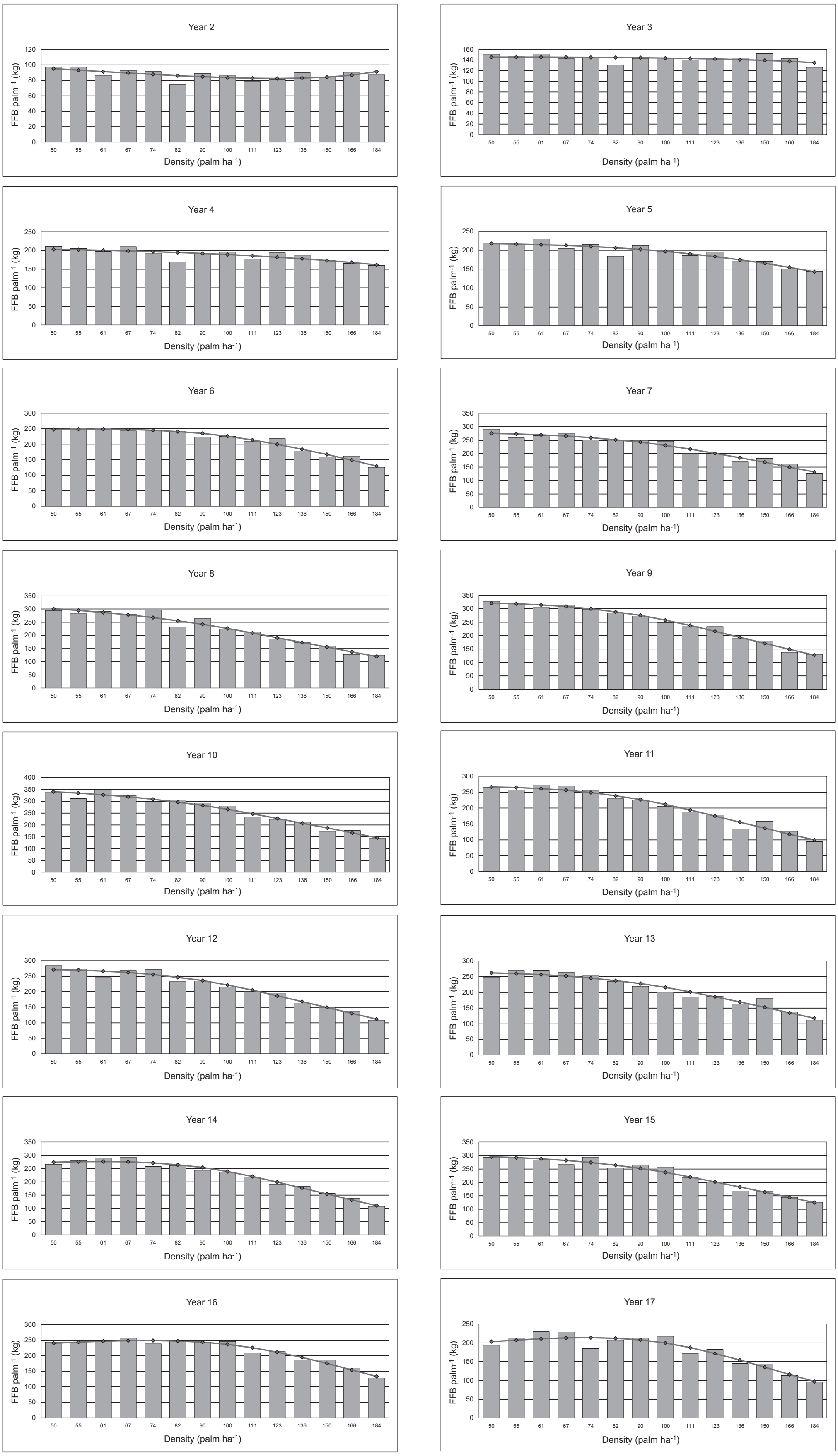
Plots consisted of 10 rows each with 20 palms row^{-1}. Recording was carried out on 12 palms in each plot.

RESULTS AND DISCUSSIONS

Experiment 1: Spacing and Fertilizer Requirements for Palms on Inland Sedentary Soils

Effect of density - FFB yields. The FFB yield per palm (in kg) and per hectare (in t) trends with density up to the 19th year of planting (17 years of harvesting) as illustrated in *Figures 1* and *2* respectively. The expected yields are calculated from fitted Holiday equations and are plotted as fitted curve in the respective diagram. At the range of densities evaluated in this experiment, there is minimal interpalm competition up to the third year of harvesting (fifth year of planting). From the fourth year of harvesting onwards, yield per palm declines progressively with density. Interpalm competition occurs rapidly in the following years and by the seventh year of harvesting, stabilizes at 123 palms ha^{-1}. There is no competition at densities below 123 palms ha^{-1} for the remainder of the planting cycle.

In the absence or at minimal interpalm competition, yield per hectare increases linearly with density and the highest yields are at the highest densities. During the first four years of harvesting,



Note: * Fitted curve for each year derived from Holiday equation.

Figure 1. Experiment 1 - the effects of planting density on fresh fruit bunch (FFB) yields (kg palm^{-1}) during the first 17 years of production in oil palms planted on an inland soil.

Note: * Fitted curve for each year derived from Holiday equation.

Figure 2. Experiment 1 - the effects of planting density on fresh fruit bunch (FFB) yields (t ha^{-1}) during the first 17 years of production in oil palms planted on an inland soil.

the current optimum density (COD) is at the higher densities of 166 – 184 palms ha^{-1} and gradually shifts to the stable COD at 136 palms ha^{-1} at sixth year of harvest and beyond. Cumulative yield per hectare (*Figure 3*) follows a similar trend to annual yields. The highest cumulative yield (agronomic optimum density, AOD) are at the higher densities of 166 – 184 palms ha^{-1} up to the seventh year of harvesting and shifts to 150 palms ha^{-1} from the eighth to the 17th year of harvest as palms age.

Effects of fertilizer. The effects of density and fertilizers on annual fresh fruit bunch (FFB) yields (t ha^{-1}) during the first 17 years of harvesting is illustrated in *Figure 4*. In the early years of harvesting, the effects of fertilizers are only apparent at the higher densities, with higher yields at the higher fertilizer rates. With increasing age, a response at lower densities becomes apparent and from the seventh year of harvesting, responses to fertilizers is evident at all densities. Similar trends are observed on cumulative yields (*Figure 5*). Based on the yield curves, there is no apparent density – fertilizer interactions in most years. This agrees with the findings of Goh (1982) and, Pamim and Harris (1986) who also found no interaction between fertilizer rates and density. With the absence of interaction it may not be necessary to increase fertilizer applications in proportion to increased density, but rather maintain current fertilizer levels on a per unit area basis regardless of density.

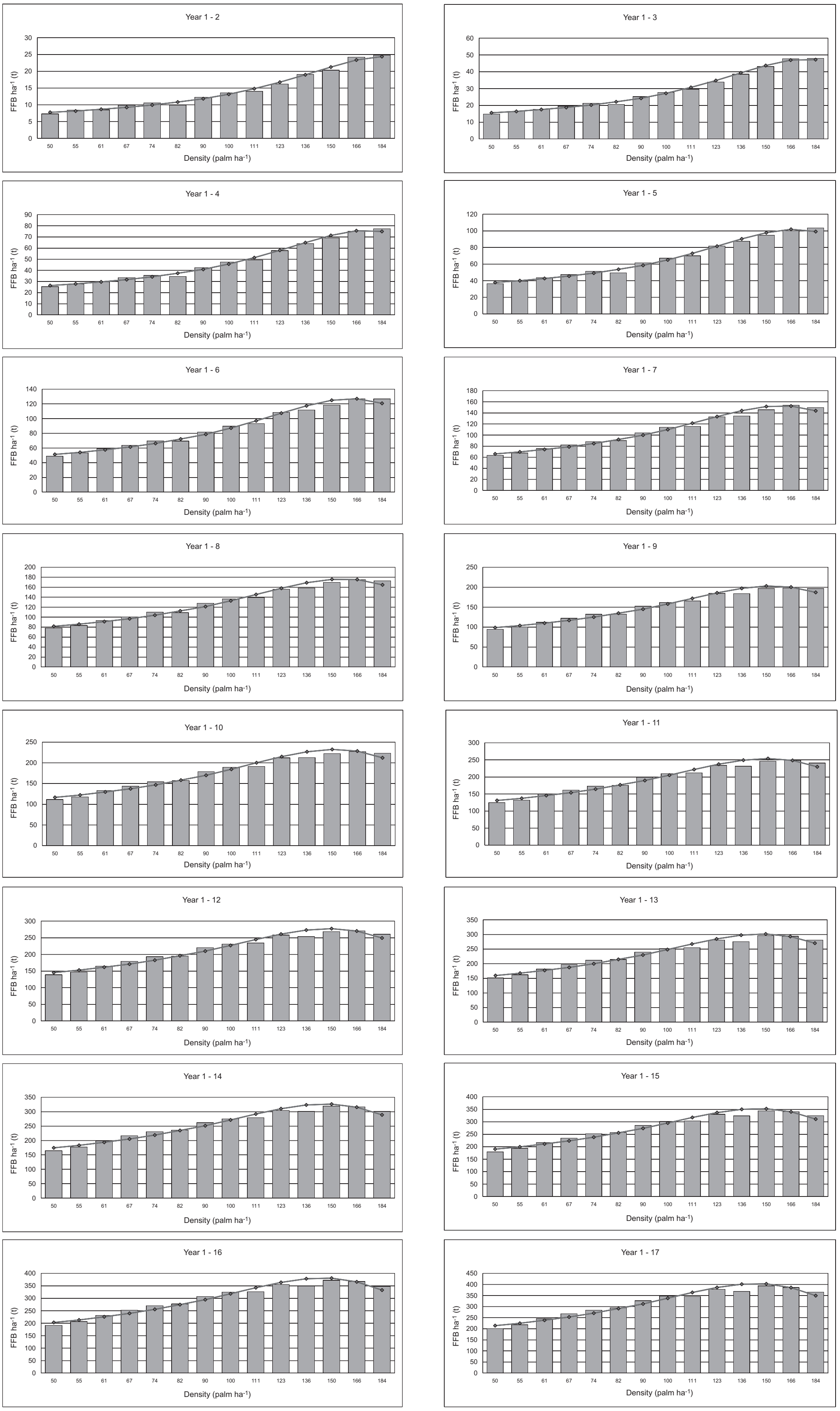
Bunch analysis. The effects of planting density on the bunch components during the 10th – 13th year from planting are summarized in *Table 1*. The regression analysis indicates that the bunch weight is negatively correlated to density (significant at 1% level). Except for wet mesocarp to fruit, all the other fruit components are positively correlated with density. Wet mesocarp to fruit is not affected by density. The economic components of oil and kernels are highly correlated to density (at p = 0.001 and p = 0.01 respectively), which implies that the economic optimum density (in term of products) for oil and kernels are higher than that for FFB. The improvement in oil and kernels is most likely due to the improvements in fruit set.

Breure *et al.* (1990), Donough and Kwan (1991) and Rao *et al.* (1992) reported significant positive correlations between density and oil and kernels contents. They attributed the higher oil and kernels to better fruit set at the higher densities. Corley (1973) and Corley *et al.* (1973) showed no difference between densities in oil content of bunches in trials in Peninsular Malaysia. The discrepancy may be attributed to Corley's analysis being carried out during the pre-weevil period. Breure *et al.* (1990) similarly detected no effect on bunch components before the introduction of weevils in Papua New Guinea. The better fruit set at the higher densities was attributed to the better efficiency of the pollinating weevils due to the cooler shaded conditions at high densities (Breure *et al.*, 1990). Consequently, the economic optimum based on oil and kernel will be higher than that based on FFB. However, within the limits of the commercial range of densities, there is little difference in the ratio of

TABLE 1. EXPERIMENT. 1 - THE EFFECTS OF DENSITY ON BUNCH COMPONENTS IN 10 - 13 YEAR OLD PALMS ON AN INLAND SEDENTARY SOIL

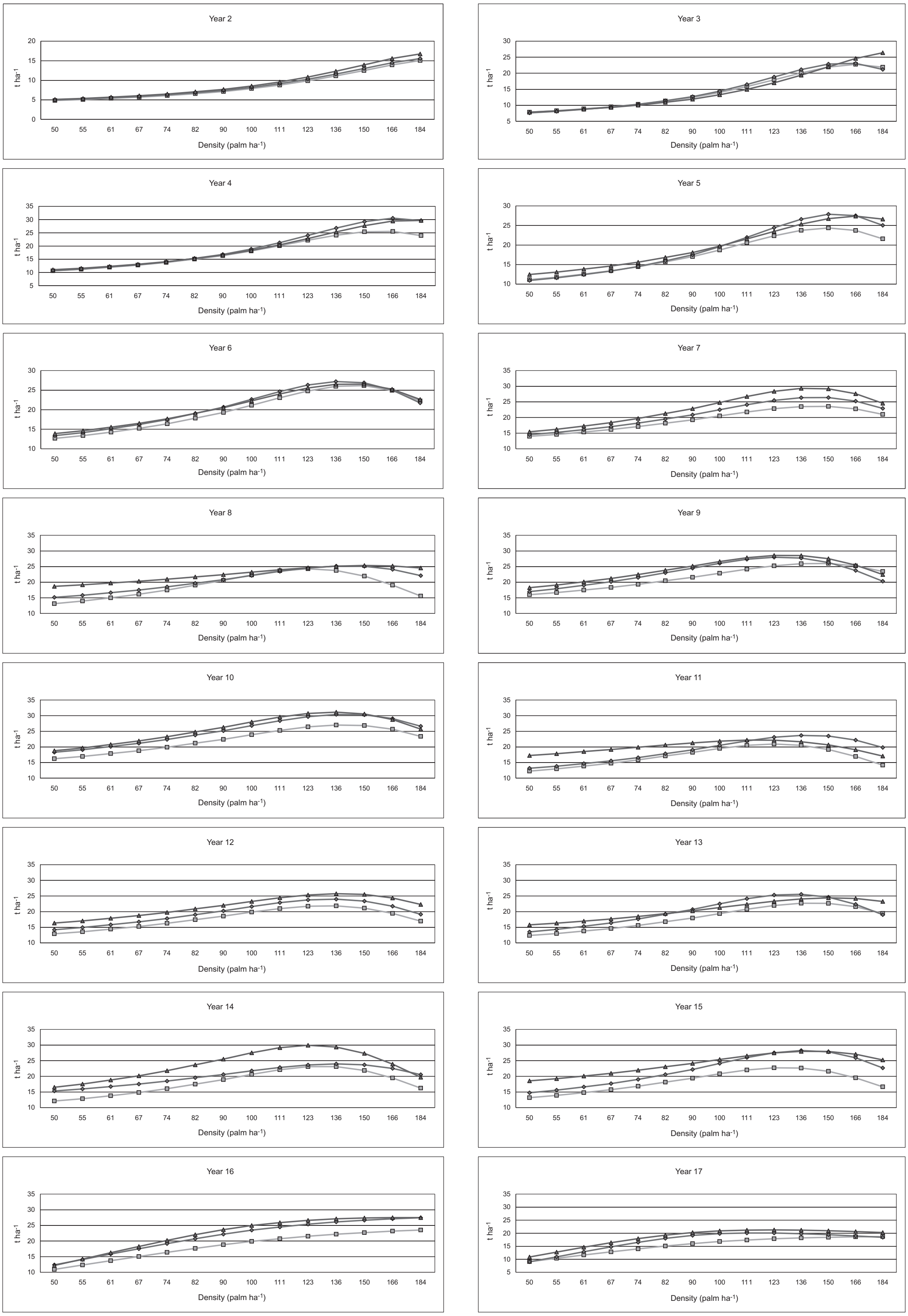
Density (palms ha^{-1})	Total bunch No. analyse	Av. B. wt. (kg)	Av. Fr. wt. (g)	FF/B (%)	WM/FF (%)	O/WM (%)	O/DM (%)	K/B (%)	O/B (Tf) (%)	Palm product (%)
184	53	22.46	9.08	67.31	77.67	45.83	75.43	6.75	24.65	28.70
166	52	25.80	9.21	68.04	77.70	45.27	75.66	6.50	24.50	28.40
150	46	25.59	9.17	66.01	78.40	44.58	75.39	6.25	23.79	27.55
136	54	26.67	9.02	66.75	78.21	45.18	75.41	6.08	24.27	27.92
123	47	26.51	8.49	65.51	78.93	44.20	75.25	6.09	23.73	27.39
100	51	28.80	8.98	65.31	79.20	44.51	75.27	6.00	23.78	27.38
82	56	28.49	8.19	65.44	78.00	44.05	74.71	6.20	23.17	29.89
61	52	27.86	8.76	64.85	78.49	43.91	74.78	5.88	23.08	26.61
50	60	27.90	8.26	63.28	78.80	44.39	74.90	5.83	23.06	26.56
	R - squared	0.70**	0.56*	0.82***	0.33ns	0.68**	0.78**	0.76**	0.88***	0.17ns

Notes: ns - Not significant.
* - Significant at 5% level.
** - Significant at 1% level.
*** - Significant at 0.1% level.
FF - fertile fruit
O - oil
WM - wet mesocarp
DM - dry mesocarp
K - kernel
B - bunch
Tf - total fruits



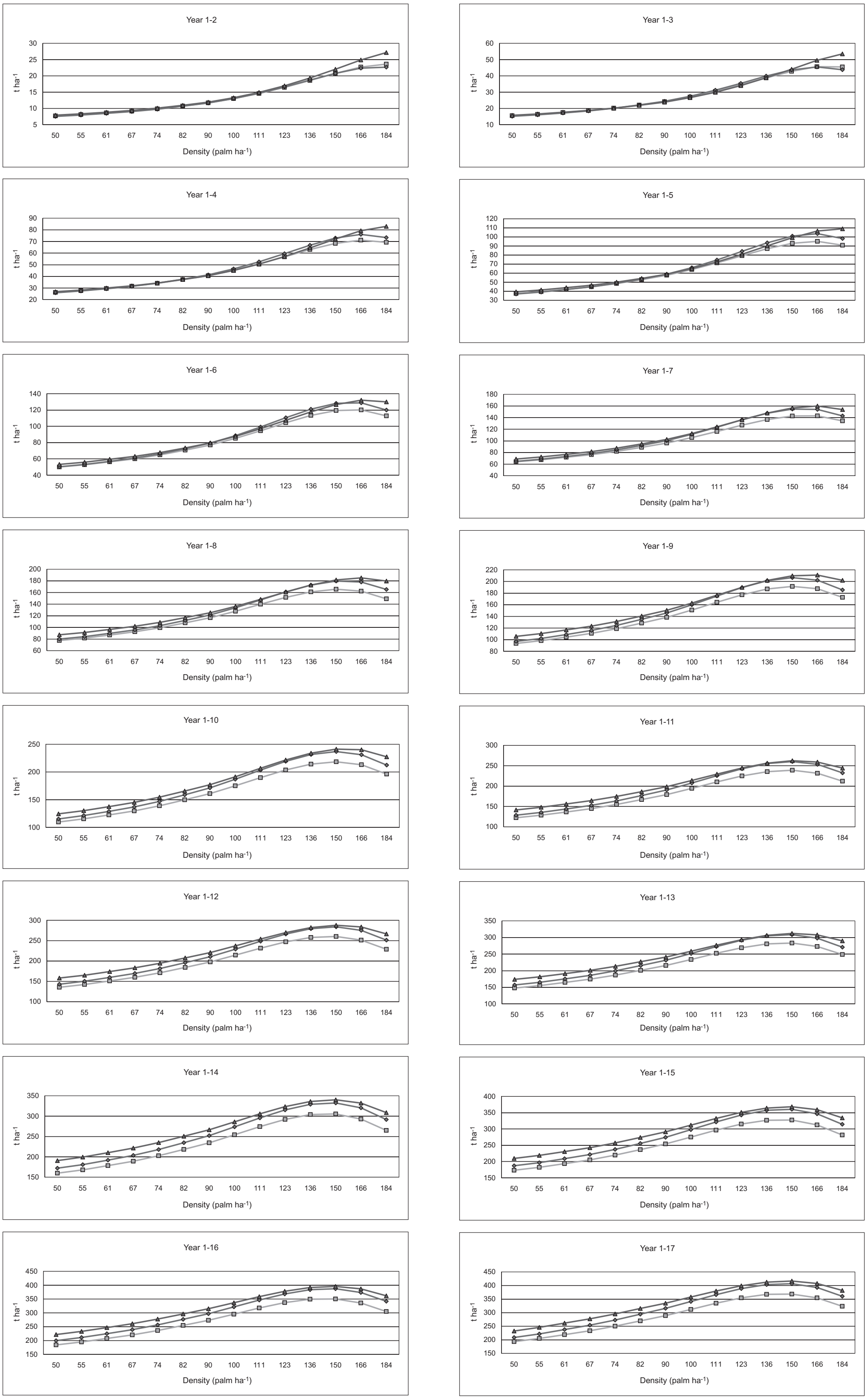
Note: * Fitted curve for each year derived from Holiday equation.

Figure 3. Experiment 1 - the effects of planting density on cumulative yields (t ha^{-1}) during the first 17 years of production in oil palms planted on an inland soil.



Notes: F 1 □ = Half normal estate fertilizer rate.
F 2 ◆ = Normal estate fertilizer rate.
F 3 ▲ = Twice normal estate fertilizer rate.
* Yields are calculated from fitted Holiday equations.

Figure 4. Experiment 1 - the effects of density and fertilizer level on annual fresh fruit bunch (FFB) yields (t ha^{-1}) during the first 17 years of production in oil palms planted on an inland soil.



Notes: F 1 ☐ = Half normal estate fertilizer rate.
F 2 ◆ = Normal estate fertilizer rate.
F 3 ▲ = Twice normal estate fertilizer rate.
* Yields are calculated from fitted Holiday equations.

Figure 5. Experiment 1 - the effects of density and fertilizer levels on cummulative fresh fruit bunch (FFB) yields (t ha^{-1}) during the first 17 years of production in oil palms planted on an inland soil.

palm products to bunch at 136 – 184 palms ha^{-1} and as such, the economic optimum based on FFB will still be valid for this trial.

Economic analysis. The cumulative discounted profits up to the 19th year of planting, at a discounting rate of 10% and at five levels of FFB prices are summarized in *Table 2* (see *Appendix 1* for cost assumptions adopted). At very low FFB prices of RM 200 t^{-1} and less, the economic optimum density (EOD) is at 136 palms ha^{-1} at manuring at half the normal estate rate. With increase in FFB prices, at RM 240 t^{-1}, the EOD shifts to a higher density of 150 palms ha^{-1} with manuring at half normal estate rate continuing to be optimal. For FFB prices greater than RM 280 t^{-1}, the COD is at 150 palms ha^{-1} with normal fertilizer inputs. Though the cash flow analysis is only up to the 19th year of planting, the trend is expected to remain the same for the remainder of the planting cycle, as yield differentials have stabilized as of the 10th year of harvesting. At the range of densities tested, the higher oil and kernels extractions at the higher densities will also result in higher returns than that computed for FFB. Hence for this environment, whilst the stable COD is at 136 palms ha^{-1}, the EOD is at 150 palms ha^{-1} which is the current commercial density. Even though there is an increase in oil and kernel extractions with density, the total oil and kernels yield per hectare is still optimum at the agronomic optimum of 150 palms ha^{-1} in view of the higher FFB yields compared to the higher densities. The advantage of the higher yields at higher COD and AOD during the early production phases did not have the advantage in oil and kernel increments.

Experiment 2: Spacing and Fertilizer Requirements for Palms on Coastal Alluvial Soils

Effect of density - FFB yields. The FFB yield per palm (in kg) and per hectare (in t) trends with density up to the 18th year of planting (16 years of harvesting) are illustrated in *Figures 6* and *7* respectively. The expected yields are calculated from fitted Holiday equations and are plotted as fitted curve in the respective diagram. As illustrated in *Figure 6*, competition is not yet evident in the first year of harvesting and consequently, yield per palm are comparable at all densities. In the second year of harvesting, competition sets in at 300 palms ha^{-1} and yield per palm is lower that at the other densities. In subsequent years, as competition increases with age, competition sets in at lower densities and increases in intensity at the higher densities. This results in a declining yield trend with increase in density. However, at 13th year of harvesting and beyond, yield per palm at the higher densities begin to pick up again, indicating a lesser degree of interpalm competition than that as the earlier years. This may be attributed to the better light interception at the later stage due to palm height segregation (Breure, 1988). Chen *et al.* (1989) reported that the amount of the light penetration under oil palm canopy decreases with age up to 13th year of planting. Beyond that, the light penetration increases with age.

In the absence or at low levels of competition, yield per hectare increases with density. As competition sets in early at the very high densities, the density giving the highest yield (COD) is at 246 palms ha^{-1} during the first two years of harvesting. As competition increases with age, the COD shifts to lower densities and by the eighth year of harvesting, the COD is at 182 palms ha^{-1} and maintained up to 12th year of harvesting. After which, it is shifted to higher densities and by the 16th year of harvesting, the COD is at 201 – 222 palms ha^{-1}.

The effect of density on cumulative yield per hectare is illustrated in *Figure 8*. The AOD during the first three years of harvesting is at 246 palms ha^{-1} and at 222 palms ha^{-1} up to the 12th year of harvesting. After which, it is shifted to 201 palms ha^{-1} up to 16th year of harvesting. Yield trends to date therefore suggests that higher than conventional densities may be a viable option.

Effects of fertilizer. The effects of density and fertilizers on FFB yields are summarized in *Figure 9*. As the fertilizer per unit area is based on the rate per palm at 136 palms ha^{-1}, the fertilizer received on a per palm basis are different at different densities. The order of decreasing fertilizer levels (as received by each palm) at the various density ranges is summarized as follows:

90 – 134 palms ha^{-1}	F3 > F2 > F1
148 – 272 palms ha^{-1}	F3 > F1 > F2
300 palms ha^{-1}	F1 > F3 > F2

(Where F1 = fertilizer on a per palm basis; F2 = fertilizer on per unit area equivalent to rate at 136 palms ha^{-1}; F3 = 2 times of F2).

The effects of density are examined in these groupings due to the quantitative differences in fertilizer inputs. At 90 – 134 palms ha^{-1} yields at F2 are consistently higher than the other fertilizer treatments in all the 16 years of production. Yield response is quadratic with fertilizer rates at this density range. There is no density-fertilizer interactions observed here.

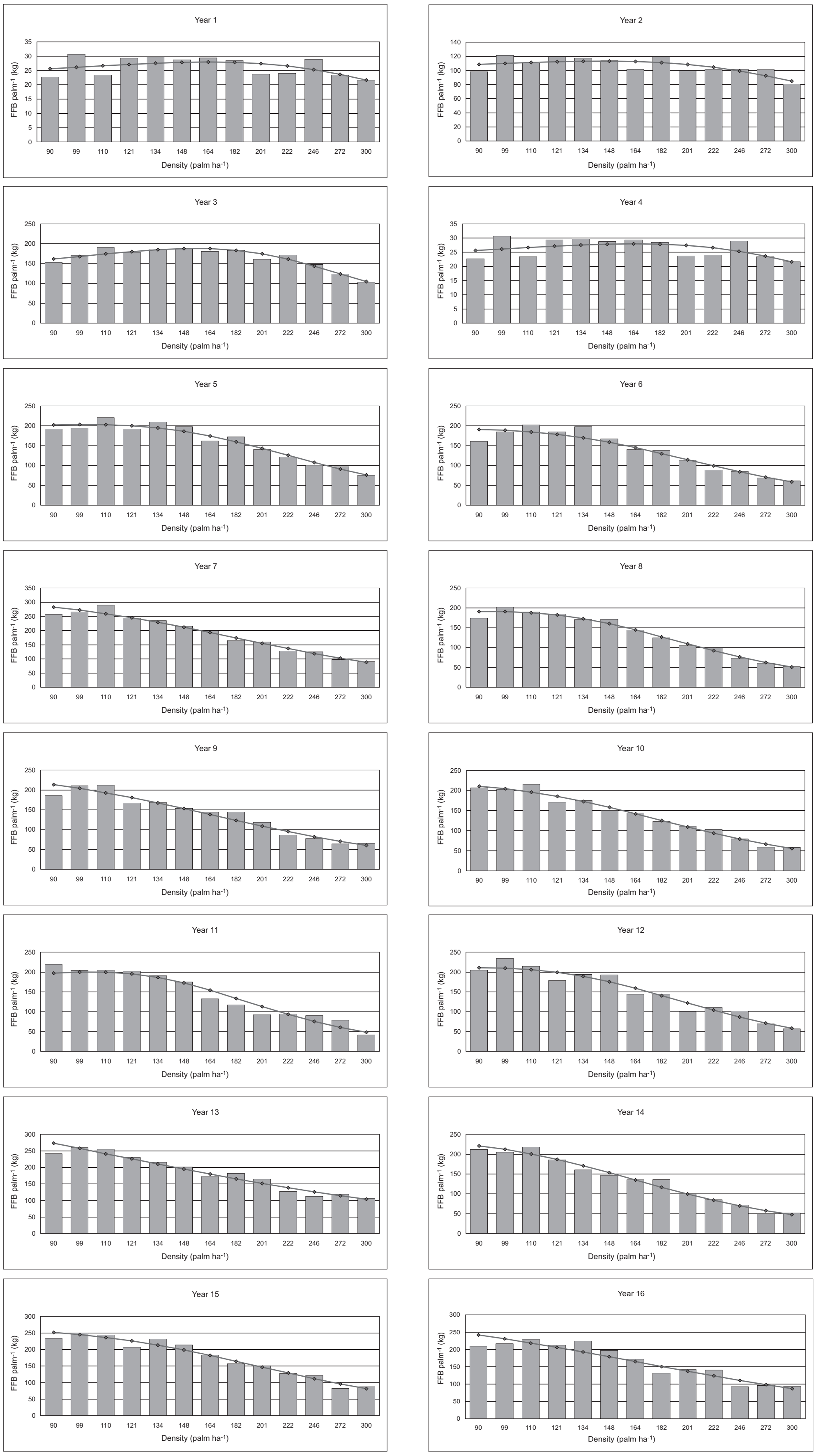
At the higher density range, 148 – 272 palms ha^{-1}, the response to fertilizers is very variable on the yearly basis. In term of cumulative yields (*Figure 10*), at 148 – 164 palms ha^{-1}, highest yields are at lowest fertilizer inputs (F2), whilst at 182 – 272 palms ha^{-1} highest yield is at highest fertilizer inputs (F3).

At extremely high density of 300 palms ha^{-1}, the response to fertilizer is very variable with no clear trend over the 16 years of production. The

TABLE 2. EXPERIMENT 1 - DISCOUNTED CASH FLOW ANALYSIS (DCF) UP TO THE 19TH YEAR OF PLANTING ON VARIOUS PLANTING DENSITY OPTIONS IN OIL PALM PLANTING ON AN INLAND SEDENTARY SOILS

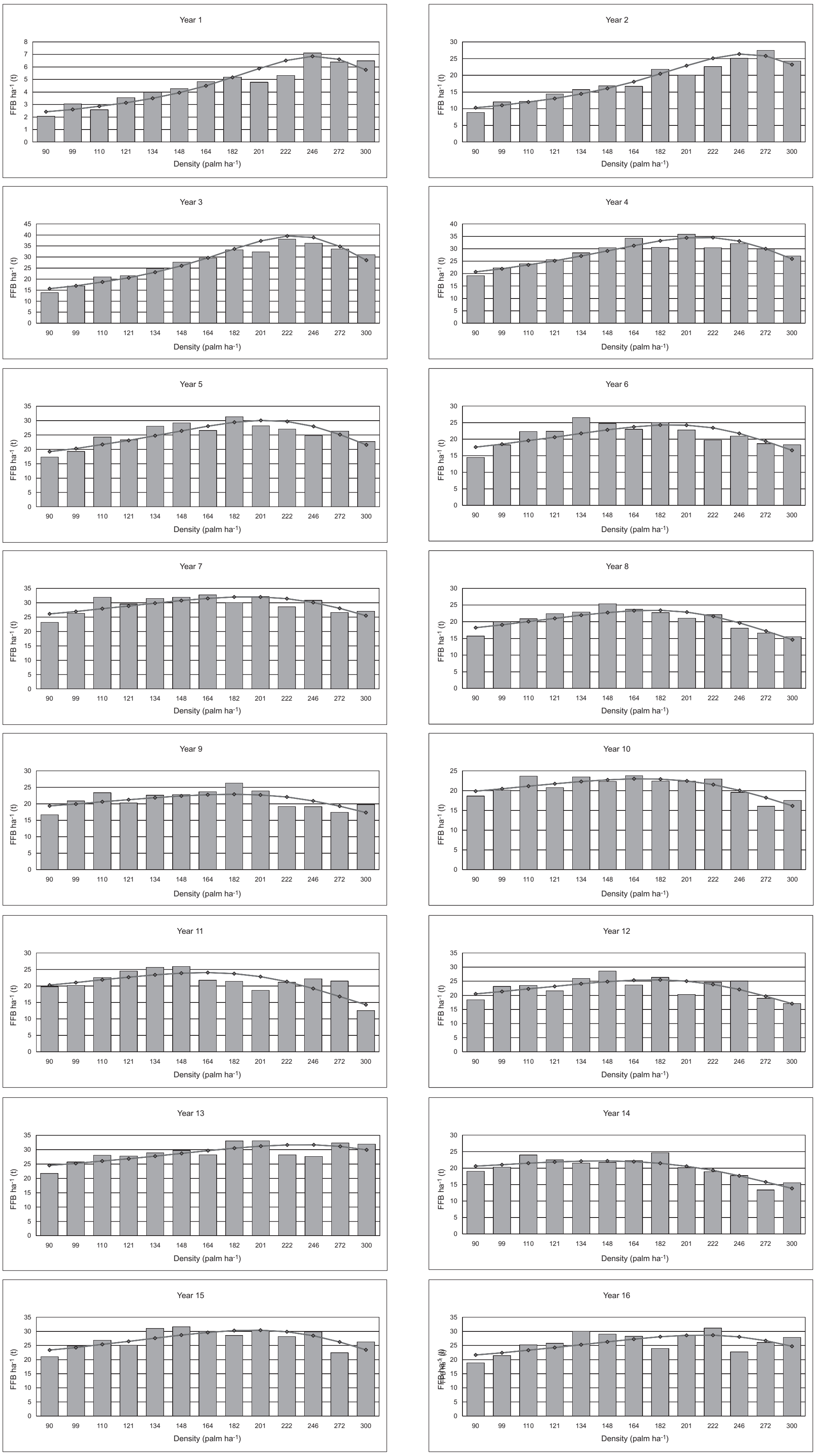
		FFB price (RM t^{-1})				
		160	200	240	280	320
Density (palm ha^{-1})	Manuring treatment	Net Present Values @ 10% discount rate (RM ha^{-1})				
184	0.5 NEF	-507	4 690	9 887	15 084	20 281
166	0.5 NEF	-90	5 102	10 294	15 487	20 679
150	0.5 NEF	194	5 354	10 514	15 674	20 834
136	0.5 NEF	312	5 401	10 490	15 579	20 668
123	0.5 NEF	261	5 233	10 204	15 176	20 148
111	0.5 NEF	-9	4 782	9 572	14 362	19 153
100	0.5 NEF	-466	4 090	8 646	13 202	17 758
90	0.5 NEF	-1 091	3 183	7 458	11 732	16 007
82	0.5 NEF	-1 740	2 262	6 263	10 264	14 266
74	0.5 NEF	-2 515	1 172	4 858	8 545	12 232
67	0.5 NEF	-3 288	92	3 473	6 854	10 235
61	0.5 NEF	-4 009	-909	2 191	5 290	8 390
55	0.5 NEF	-4 773	-1 968	837	3 641	6 446
50	0.5 NEF	-5 433	-2 883	-332	2 219	4 770
184	NEF	-2 180	3 622	9 423	15 225	21 026
166	NEF	-1 607	4 128	9 863	15 598	21 333
150	NEF	-1 215	4 423	10 061	15 699	21 337
136	NEF	-1 022	4 483	9 987	15 491	20 996
123	NEF	-1 013	4 312	9 637	14 962	20 286
111	NEF	-1 198	3 898	8 994	14 091	19 187
100	NEF	-1 558	3 266	8 091	12 916	17 741
90	NEF	-2 062	2 458	6 979	11 499	16 020
82	NEF	-2 592	1 644	5 880	10 116	14 352
74	NEF	-3 233	683	4 598	8 513	12 429
67	NEF	-3 883	-278	3 327	6 933	10 538
61	NEF	-4 499	-1 178	2 143	5 464	8 784
55	NEF	-5 164	-2 143	877	3 898	6 918
50	NEF	-5 749	-2 989	-228	2 532	5 292
184	2 NEF	-8 261	-2 141	3 979	10 099	16 219
166	2 NEF	-7 340	-1 397	4 545	10 488	16 430
150	2 NEF	-6 511	-723	5 065	10 853	16 640
136	2 NEF	-5 846	-214	5 419	11 052	16 684
123	2 NEF	-5 340	113	5 565	11 018	16 471
111	2 NEF	-5 017	222	5 462	10 701	15 941
100	2 NEF	-4 884	107	5 098	10 090	15 081
90	2 NEF	-4 923	-210	4 503	9 216	13 930
82	2 NEF	-5 079	-628	3 822	8 273	12 724
74	2 NEF	-5 349	-1 198	2 953	7 104	11 255
67	2 NEF	-5 677	-1 819	2 039	5 897	9 756
61	2 NEF	-6 025	-2 439	1 147	4 733	8 319
55	2 NEF	-6 432	-3 137	158	3 453	6 747
50	2 NEF	-6 820	-3 785	-749	2 287	5 323

Notes: Highest NPV underlined.
NEF - Normal estate fertilizer rate.
* Yields are calculated from fitted Holiday equation.



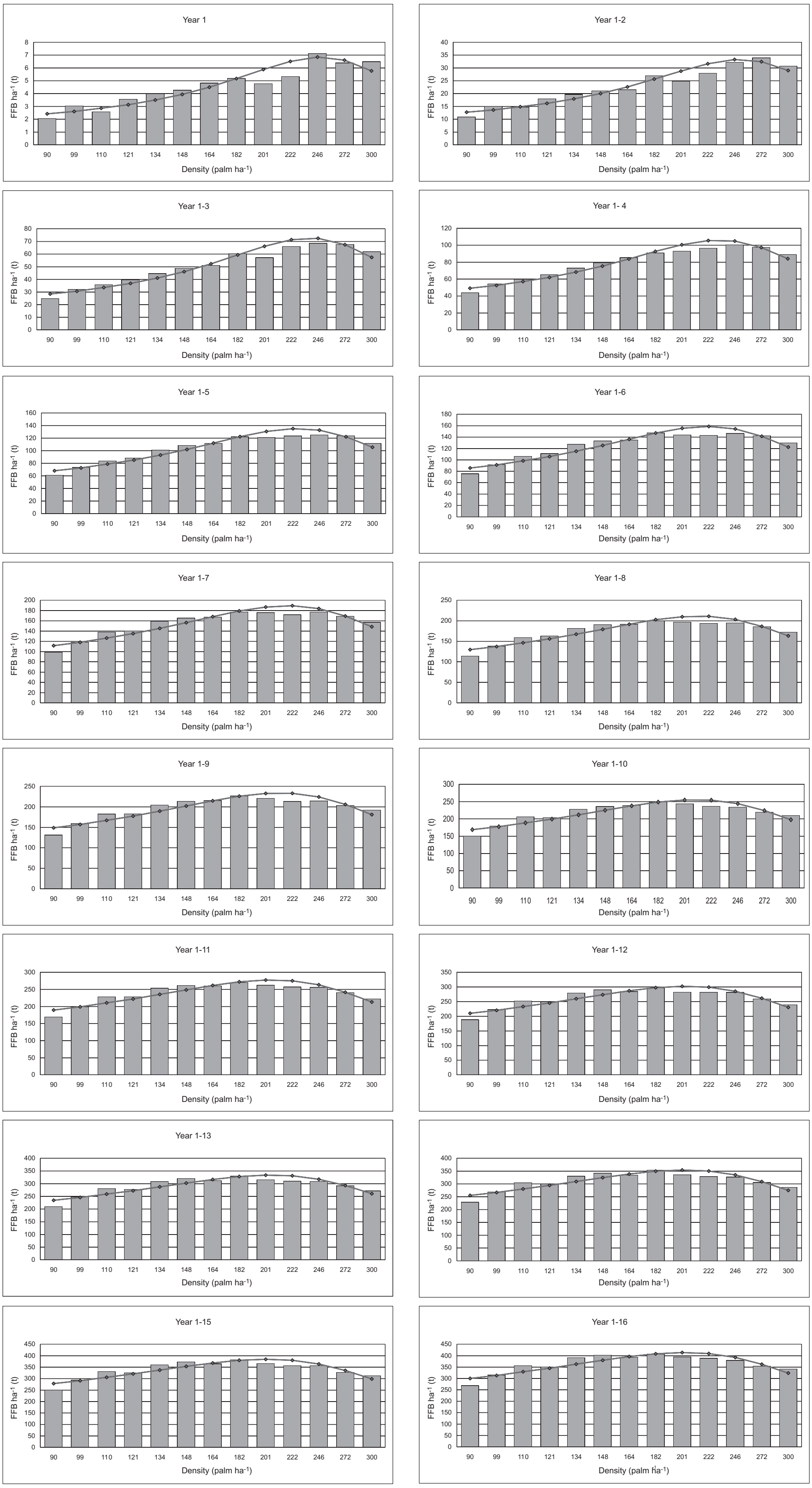
Note: * Fitted curve for each year derived from Holiday equation.

Figure 6. Experiment 2 - the effects of planting density on fresh fruit bunch (FFB) yields (kg palm^{-1}) during the first 16 years of production in oil palms planted in coastal soil.



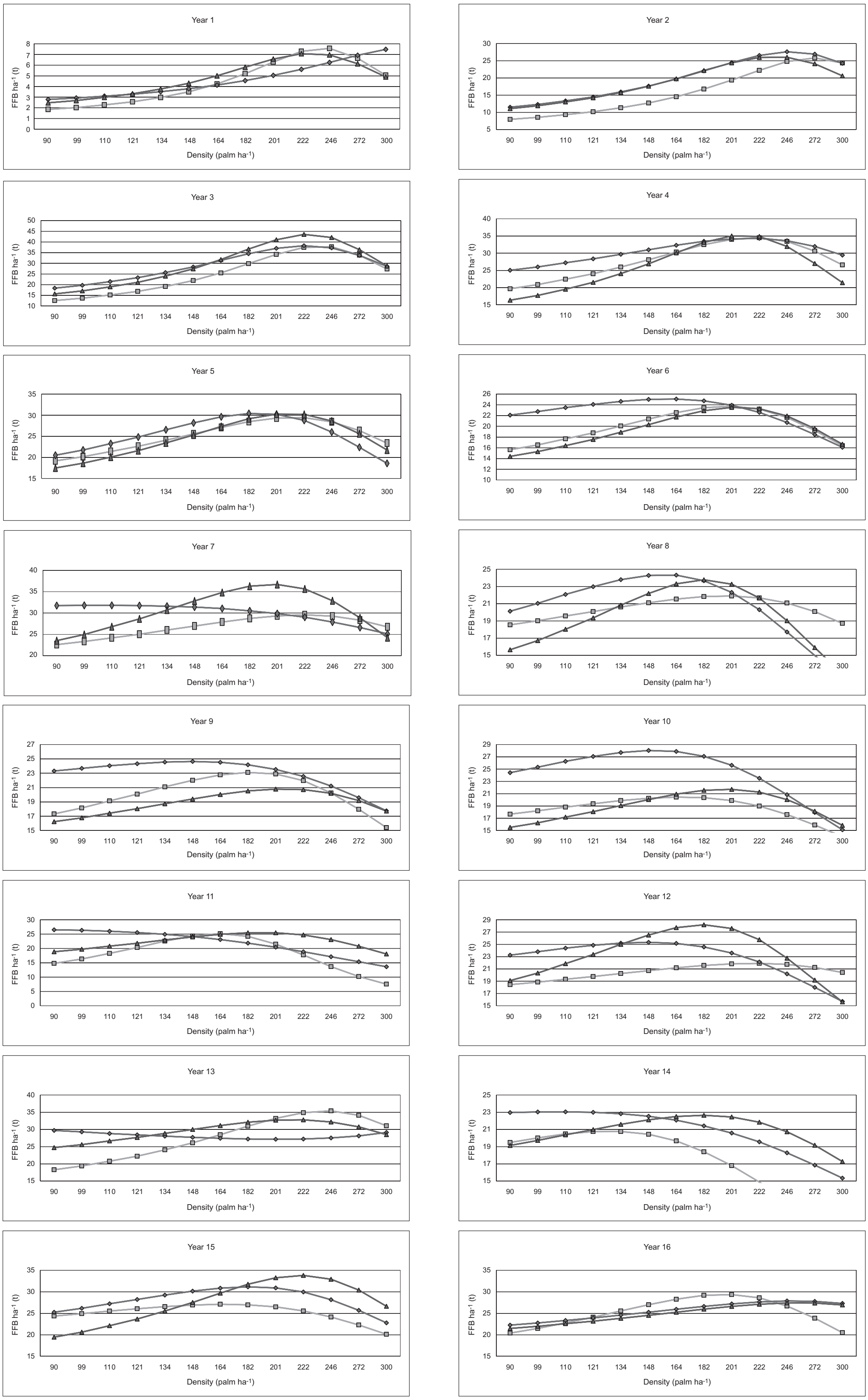
Note: * Fitted curve for each year derived from Holiday equation.

Figure 7. Experiment 2 - the effects of planting density on fresh fruit bunch (FFB) yields (t ha^{-1}) during the first 16 years of production in oil palms planted in coastal soil.



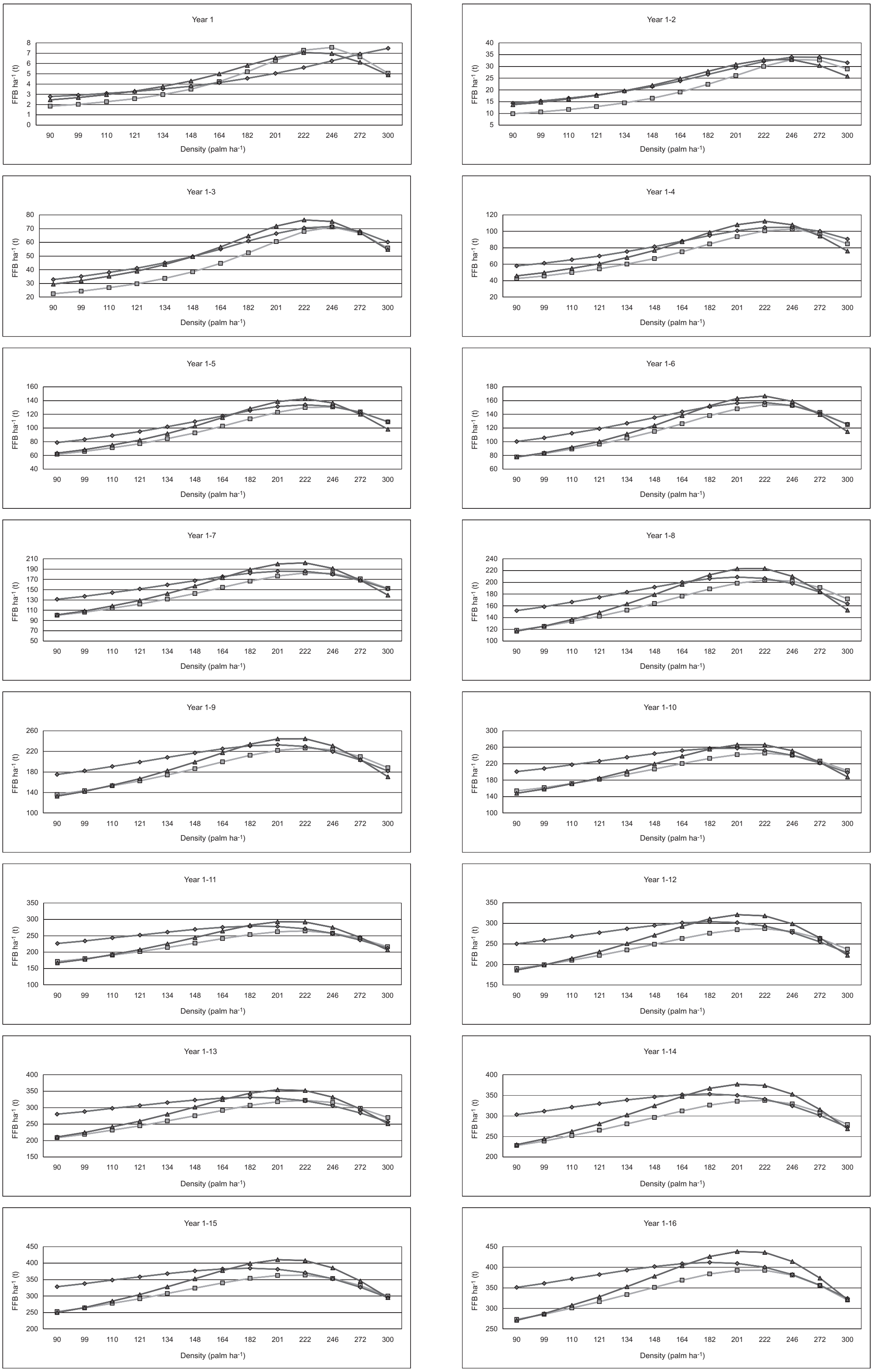
Note: * Fitted curve for each cumulative year derived from Holiday equation.

Figure 8. Experiment 2 - the effects of planting density on fresh fruit bunch (FFB) yields (t ha^{-1}) during the first 16 years of production in oil palms planted in coastal soil.



Notes: F 1 □ = Fertilizer applied at normal estate rate on a per palm basis.
F 2 ◆ = Fertilizer applied at normal estate rate on per unit area basis equivalent to rate at 136 palms ha^{-1}.
F 3 ▲ = Double the rate at F2 on a per unit area basis.
* Yields are calculated from fitted Holiday equations.

Figure 9. Experiment 2 - the effects of planting density and fertilizers on annual fresh fruit bunch (FFB) yields (t ha^{-1}) during the first 16 years of production in oil palms planted in coastal soil.



Notes: F 1 ☐ = Fertilizer applied at normal estate rate on a per palm basis.
F 2 ◆ = Fertilizer applied at normal estate rate on per unit area basis equivalent to rate at 136 palms ha^{-1}.
F 3 ▲ = Double the rate at F2 on a per unit area basis.
* Yields are calculated from fitted Holiday equations.

Figure 10. Experiment 2 - the effects of planting density and fertilizers on cummulative fresh fruit bunch (FFB) yields (t ha^{-1}) during the first 16 years of production in oil palms planted in coastal soil.

cumulative yield is comparable in all fertilizer rates. The AOD is similar at F1 and F3, at 201-222 palms ha^{-1}, though yields at the optimum densities are different. At F2, the AOD is at 182 palms ha^{-1}.

On the question of whether fertilizers should be applied on a per palm or per unit area basis, the results show that up to 222 palms ha^{-1}, yields are higher with manuring on per unit area compared to manuring on a per palm basis. There is little difference in yields at densities greater than 246 palms ha^{-1} with regards to manuring regimes. Breure (1982), found that fertilizer responses were reduced with increase in density as palms aged. Hence, whilst manuring rates need to be increased at the higher densities, it may not be in direct proportion to stand per hectare. This will make high density planting more attractive as manuring is a high cost input. However, to fully exploit the yield potential of high density plantings, the optimum fertilizer requirements for the environment must be established, as results show that the optima can be further increased with the correct fertilizer regimes.

Bunch analysis. The effect of planting density on bunch components at the eighth year of planting is summarized in *Table 3*. Results are similar to that observed in Experiment 1. Bunch weight is negatively correlated to planting density, whilst oil to wet mesocarp, kernel and oil to bunch ratios show positive correlation with density. The rest of the fruit components are not affected by density.

Consequent to the higher oil and kernel content, palm product to bunch ratio (oil and kernel in oil equivalent) also increases with density. Because FFB yield trend is quadratic with density, the oil and kernel yield per hectare will show similar trend. The AOD for oil and kernel will therefore be higher than that for FFB and will also decline with age.

Whilst the differences in palm product to bunch ratio is high between the extreme densities, the differences at the 148 to 201 palms ha^{-1} range is small and the economic optimum will be largely determined by FFB yields, as in the later stages. FFB yield differences will be greater due to increase interpalm competition. The small gain in oil and kernel content is insufficient to compensate the greater reduction in FFB at the high densities.

Economic analysis. The discounted cash flow analysis for various density options up to the 18th year of planting are summarized in *Table 4*. Generally, at equivalent densities, discounted profits are higher at fertilizers applied on per unit are than on a per palm basis. This is primarily due to the higher fertilizer inputs on a per palms basis with concomitant higher cost without improvement in

TABLE 3. EXPERIMENT 2 - THE EFFECTS OF PLANTING DENSITY ON BUNCH COMPONENTS IN 8-YEAR-OIL PALMS PLANTED ON A COASTAL SOIL

Density (palms ha^{-1})	Total bunch No. analyse	Av. B. wt. (kg)	Av. Fr. wt. (g)	FF/B (%)	WM/FF (%)	O/WM (%)	O/DM (%)	K/B (%)	O/B (TF) (%)	Palm product (%)
300	16	11.85	11.53	63.89	80.32	49.59	77.06	5.67	26.76	30.16
272	15	11.18	10.71	63.79	79.87	48.54	75.83	5.65	25.20	28.59
246	15	12.65	11.83	64.56	80.18	49.54	77.06	5.53	25.99	29.31
222	15	12.14	15.72	64.04	78.92	50.50	77.16	5.91	26.46	30.01
201	16	12.26	10.76	61.25	81.06	49.41	77.10	5.25	24.98	28.13
182	16	13.50	10.19	62.98	80.33	46.68	75.98	5.42	24.19	27.44
164	15	14.20	10.60	61.20	78.86	45.31	74.96	5.79	22.37	25.84
148	18	13.30	10.04	62.06	80.55	47.87	76.24	5.36	24.32	27.54
134	19	13.92	10.53	63.38	79.17	47.95	75.91	5.73	24.37	27.81
121	15	14.46	10.97	56.81	80.29	46.45	75.84	4.37	21.99	24.61
110	14	13.13	10.26	58.35	81.71	48.58	76.51	4.59	24.21	26.96
99	17	13.86	12.04	63.33	78.25	47.46	75.96	4.93	24.88	27.85
90	17	14.93	10.91	62.85	81.32	47.59	75.90	4.54	24.82	27.54
	R-squared	0.74***	0.08ns	0.26ns	0.00ns	0.31*	0.24ns	0.47**	0.37*	0.47**

Notes: ns - Not significant.
* - Significant at 5% level.
** - Significant at 1% level.
*** - Significant at 0.1% level.

FF - fertile fruit
O - oil
WM - wet mesocarp
DM - dry mesocarp

K - kernel
B - bunch
TF - total fruits

TABLE 4. EXPERIMENT 2 - DISCOUNTED CASH FLOW ANALYSIS UP TO THE 18TH YEAR OF PLANTING ON VARIOUS PLANTING DENSITY OPTIONS IN OIL PALMS PLANTED ON A COASTAL SOIL

Density (palm ha^{-1})	Fertilizer levels	FFB price (RM t^{-1}) 160	200	240	280	320
		Net present values @ 10% discount rate (RM ha^{-1})				
300	F1	-9 495	-4 494	507	5 507	10 508
272	F1	-6 167	-478	5 211	10 900	16 589
246	F1	-3 682	2 449	8 581	14 713	20 844
222	F1	-2 243	4 019	10 282	16 544	22 806
201	F1	-1 679	4 472	10 622	16 772	22 923
182	F1	-2 616	2 962	8 540	14 119	19 697
164	F1	-1 838	3 740	9 319	14 897	20 475
148	F1	-2 197	3 039	8 276	13 512	18 749
134	F1	-2 583	2 330	7 244	12 158	17 072
121	F1	-2 964	1 643	6 250	10 858	15 465
110	F1	-3 281	1 068	5 418	9 767	14 117
99	F1	-3 580	518	4 615	8 713	12 810
90	F1	-3 804	94	3 992	7 890	11 788
300	F2	-3 235	1 751	6 736	11 722	16 707
272	F2	-1 274	4 306	9 886	15 466	21 046
246	F2	228	6 256	12 284	18 312	24 340
222	F2	1 126	7 409	13 691	19 974	26 257
201	F2	<u>1 426</u>	<u>7 774</u>	<u>14 122</u>	<u>20 469</u>	<u>26 817</u>
182	F2	1 282	7 553	13 824	20 096	26 367
164	F2	793	6 878	12 963	19 047	25 132
148	F2	111	5 949	11 786	17 624	23 462
134	F2	-631	4 944	10 519	16 093	21 668
121	F2	-1 398	3 907	9 213	14 518	19 823
110	F2	-2 078	2 989	8 055	13 122	18 189
99	F2	-2 768	2 057	6 883	11 708	16 533
90	F2	-3 330	1 299	5 928	10 557	15 186
300	F3	-8 664	-3 741	1 181	6 104	11 027
272	F3	-5 770	51	5 871	11 692	17 513
246	F3	-3 479	3 046	9 572	16 097	22 622
222	F3	-2 317	4 549	11 415	18 281	25 148
201	F3	-2 331	4 497	11 326	18 155	24 984
182	F3	-3 122	3 420	9 962	16 505	23 047
164	F3	-4 362	1 749	7 860	13 971	20 082
148	F3	-5 695	-42	5 610	11 263	16 916
134	F3	-6 934	-1 706	3 522	8 751	13 979
121	F3	-8 084	-3 250	1 584	6 417	11 251
110	F3	-9 029	-4 519	-10	4 500	9 009
99	F3	-9 931	-5 733	-1 534	2 665	6 864
90	F3	-10 632	-6 674	-2 717	1 240	5 198

Notes: F1 - Fertilizer applied at normal estate rate on per palm basis.
F2 - Fertilizer applied at normal estate rate on per unit area basis equivalent to rate at 136 palms ha^{-1}.
F3 - Double the rate at F2 on a per unit area basis.
Highest NPV underlined.
* Yields are calculated from fitted Holliday equations.

yield. At all FFB prices tested, greatest discounted profits are obtained at 201 palms ha^{-1} with fertilizer applied at normal rate on a per unit area basis. Hence, for shorter replanting cycle of 15 – 18 years compared to normal cycle of 20 – 25 years, the economic density is at densities higher than current conventional densities. Planting at 180 – 200 palms ha^{-1} appears to be a viable high density option. Donough and Kwan

(1991) proposed similar high density planting option based on their discounted cash flow analysis carried out on their trial results.

Experiment 3: Variable Density Option on Coastal Soil Using Triangular Spacing

FFB yields. The FFB yields per palm and per hectare for the first 16 years of harvesting (18th year of planting) are summarized in *Table 5*. Systematic thinning at 14% was carried out during the seventh year of harvesting (ninth year of planting). Yield per palm improvements at the thinned equivalents at densities higher than 114 palms ha^{-1} is evident on the second year after thinning onward. But with respect to yield per hectare, yield improvements are evident only at the thinned equivalents at densities greater than 125 palms ha^{-1}. On cumulative yields up to the 16th year of harvesting, improvement in yield per hectare only recorded at thinned equivalents at densities greater than 152 palms ha^{-1}. Comparing the fixed density and the variable density options, the AOD is at the variable density option of 184 palms ha^{-1}. Within the fixed density options, the AOD is still at 184 palms ha^{-1}.

Economic analysis. Based on the results up to the 18th year of planting, discounted cash flow analysis at 10% discount rate was computed for all the density options for a range of FFB prices (*Table 6*). The cumulated discounted profits are lower at the very high and very low densities due to primarily to high cost and lower yields respectively. The EOD up to the 18th year of planting is at a fixed density option of 125 palms ha^{-1} when the FFB price is low at RM 160 t^{-1}. At higher FFB prices, RM 200 t^{-1} and above, the EOD is shifted to variable density option of 184 palms ha^{-1} thinned at ninth year of planting with 14% thinning intensity.

With respect to the fixed density options, planting at 184 palms ha^{-1} still gave the highest discounted profits when the FFB prices are higher than RM 200 t^{-1}. It is better than the current conventional planting densities, which ranges from 130 - 150 palms ha^{-1}.

Experiment 4: Variable Density Option on Coastal Soil Using Square Spacing

FFB yields. The FFB yields per palm and per hectare for the first 16 years of harvesting (18th year of planting) are summarized in *Table 7*. Systematic thinning at 25% was carried out during the ninth year of planting. Yield per palm improvements were only evident from the second year after thinning at the thinned equivalents at densities higher than 288 palms ha^{-1} and evident from the third year after thinning at densities higher than 112 palms ha^{-1}. With respect to yield per hectare, yield improvements are evident only from the fifth year after thinning at the thinned equivalents at densities higher than 180 palms ha^{-1}. On cumulative yields up to the 16th year of harvesting, improvement in yield ha^{-1} are only apparent at thinned equivalent densities greater than 210 palms ha^{-1}. Comparing the fixed and the variable density options, the AOD is at the fixed density of 131 palms ha^{-1}. Within the variable density options, starting density of 210 palms ha^{-1} appears to be the optimum.

Economic analysis. Based on the results up to the 18th year of planting, discounted cash flow analysis at 10% discount rate was computed for all the density options for a range of FFB prices (*Table 8*). Similar to Experiment 3, the cumulated discounted profits, up to the 18th year of planting, indicate lower profitability at extremely high and low densities. At all FFB prices between RM 160 and RM 320 t^{-1}, the EOD is at a fixed density option of 131 palms ha^{-1}.

Comparisons on returns between square and triangular plantings (in Experiment 3), indicate the triangular plantings to be superior both as fixed or as variable density options. Whilst square plantings may not be suitable as fixed density options, it may be considered for a variable density option as it is amenable for a two stage systematic thinning. As this experiment was only designed for a one stage thinning, further experimentation with the appropriate starting densities is required to ascertain the potential of the square option with two stage thinning.

Experiment 5: Variable Density Option on Inland Sedentary Soil Using Hexagonal Spacing

FFB yields. The FFB yields per palm and per hectare for the first 18 years of harvesting (20th year of planting) are summarized in *Table 9*. Three periods of thinning by removing complete radii from the offset circle leaving an equilateral triangular spacing at half the density were carried out at eighth, 10th and 16th year of planting respectively. On cumulative yields of post thinning up to 18th year of harvesting, yield per palm improvements are evident in all the thinned equivalent densities in all three periods of thinning.

With respect to yield per hectare, yield improvements are evident in the thinned equivalents at densities greater than 199 palms ha^{-1} at thinning period of eighth year after planting. Where thinning is at 10th year after planting, the improvements are at the thinned equivalents at densities greater than 181 palms ha^{-1}. There is no yield improvement when thinning is carried out at 16th year of planting. Comparing the fixed density and the variable density

TABLE 5. EXPERIMENT 3 - THE EFFECTS OF PLANTING DENSITY AND THINNING ON FRESH FRUIT BUNCH (FFB) YIELDS DURING THE FIRST 16 YEARS OF PRODUCTION IN OIL PALMS PLANTED ON A COASTAL SOIL

		FFB yields (kg palm^{-1})																					
Density		YR 7		YR 8		YR 9		YR 10		YR 11		YR 12		YR 13		YR 14		YR 15		YR 16		YR 1 - 16	
(palms ha^{-1})	YR 1 - 6	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin
299	388.98	112.1	34.88	46.23	93.7	46.19	83	43.71	81.65	59.7	49.26	59.36	66.78	79.08	89.06	47.48	94.27	84.15	70.2	82.29	101.85	1 049.27	1 153.63
271	475.94	79.32	70.18	53.55	93.4	79.55	121.1	44.59	68.2	58.12	51.26	37.36	118.18	56.57	111.7	44.4	38.05	89.16	105.9	56.7	131.1	1 075.26	1 385.01
246	565.02	102.83	119.5	60.54	74.13	90.29	70.94	87.56	117.38	82.45	85.84	94.81	63.02	106.63	47.16	59.02	100.75	117.52	124.13	119.92	94.38	1 486.59	1 462.25
223	598.52	95.8	159.15	78	104.25	113.8	102.35	99.7	209.3	73.2	114.78	72.7	1 37.98	97.76	105.93	71.02	109.8	144.52	194.9	80.14	125.9	1 525.16	1 962.86
203	726.56	166.15	109.89	92.96	70.45	113.4	164.25	149.96	91.65	99.36	128.15	118.73	120.76	105.13	115.06	83.85	61.59	157.08	196.4	151.1	100.95	1 964.28	1 885.71
184	841.4	181.5	144.95	135.07	132.55	111.14	134.2	189.77	244.85	109.28	140.68	107.93	195.6	161.73	166.13	106.5	108.85	169.82	258.25	110.98	173.85	2 225.12	2 541.31
167	858.08	220.71	158.09	157.4	168.5	144.77	247.63	147.77	162.06	130.58	151.39	97.12	201.85	150.92	216.89	102.63	87.63	148.81	204.56	166.63	203.5	2 325.42	2 660.18
152	852.18	186.02	266.89	142.34	125.4	140.11	204.35	148.2	211.4	143.04	208.67	123.05	176.44	134.26	180.23	110.2	195.04	216.93	252.25	158.34	167.9	2 354.67	2 840.75
138	947.68	241.13	169.42	168.29	238	189.04	194.38	195.5	203.13	164.34	249.21	133.1	227.73	191.42	184.86	131.78	163.79	242.52	286.19	172.44	149.94	2 777.24	3 014.33
125	993.58	260.89	270.01	169.91	214.42	199.52	209.92	258.27	278.83	185.12	158.66	174.96	245.9	231.55	345.4	230.44	221.99	244.02	187.54	190.66	181	3 138.92	3 307.25
114	1 022.18	284.79	269.73	204.1	236.94	196.6	162.69	283.54	268.88	224.69	262.52	151.36	194.9	223.45	263.89	198.93	295.24	222.44	282.75	153.46	199.44	3 165.54	3 459.16
103	930.68	248.93	303.68	210.39	167.25	215.02	229.3	181.07	270.25	213.73	155.5	224.42	188.58	206.79	231.07	123.77	244.2	243.89	200.35	170.25	169.65	2 968.94	3 090.51
94	990.4	288.96	303.89	214.02	236.88	230.96	274.3	242.08	308.69	261.34	214.39	247.7	250.5	240.45	302	235.13	284.19	245.50	270.38	267.56	242.69	3 464.10	3 678.31
85	920.58	301.18	320.05	217.7	206.1	247.77	221.65	314.95	270.15	175.99	182.71	184.9	216.66	308.76	227.41	218.14	210.59	274.48	261.25	250.39	183	3 414.84	3 220.15
77	953.3	291.13	373.11	195.83	220.3	283.98	253.4	261.81	314.45	236.89	220.97	228.06	220	268.14	377.56	240.08	319.48	266.29	262.65	220.65	217.1	3 446.16	3 732.32
70	969.51	280.2	286.02	197.34	205.6	251	263.05	273.2	329.1	204.42	176.78	209.15	228.14	329.28	420.98	256.87	289.79	274.91	240.65	246.07	254.6	3 491.95	3 664.22
64	911.37	279.65	302.19	244.31	292.56	234.46	303.31	247.27	319.38	204.23	222.69	249.12	351.3	261.04	315.81	186.73	243.31	238.83	344.63	231.1	355.19	3 288.11	3 961.74

		FFB yields (t ha^{-1})																					
Density		YR 7		YR 8		YR 9		YR 10		YR 11		YR 12		YR 13		YR 14		YR 15		YR 16		YR 1 - 16	
(palms ha^{-1})	YR 1 - 6	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin
299	116.30	33.52	9.47	13.82	24.08	13.81	21.33	13.07	20.98	17.85	12.66	17.75	17.16	23.64	22.89	14.20	28.19	25.16	18.04	24.61	26.18	313.73	317.28
271	128.97	21.50	17.10	14.51	21.76	21.56	28.22	12.08	15.89	15.75	11.94	10.13	27.54	15.88	26.03	12.03	10.31	24.16	24.67	15.37	30.55	291.94	342.98
246	139.00	25.30	26.53	14.89	15.71	22.21	15.04	21.54	24.88	20.28	18.20	23.32	13.36	26.23	10.00	14.52	24.78	28.91	26.31	29.50	20.01	365.70	333.82
223	133.47	21.36	32.23	17.39	20.02	25.38	19.65	22.23	40.19	16.32	22.04	16.21	26.49	21.80	20.34	15.84	24.49	32.23	37.42	17.87	24.17	340.10	400.51
203	147.49	33.73	19.87	18.87	12.33	23.02	28.74	30.44	16.04	20.17	22.43	24.10	21.13	21.34	20.14	17.02	12.50	31.89	34.37	30.67	17.67	398.74	352.71
184	154.82	33.40	24.30	24.85	20.94	20.45	21.20	34.92	38.69	20.11	22.23	19.86	30.90	29.76	26.25	19.60	20.03	31.25	40.80	20.42	27.47	409.44	427.63
167	143.29	36.86	24.75	26.29	24.26	24.18	35.66	24.68	23.34	21.81	21.80	16.22	29.07	25.20	31.23	17.14	14.63	24.85	29.46	27.83	29.30	388.35	406.79
152	129.55	28.28	37.54	21.64	16.43	21.30	26.77	22.53	27.69	21.74	27.34	18.70	23.11	20.41	23.61	16.75	29.65	32.97	33.04	24.07	21.99	357.94	396.72
138	130.78	33.28	21.99	23.22	28.32	26.09	23.13	26.98	24.17	22.68	29.66	18.37	27.10	26.42	22.00	18.19	22.60	33.47	34.06	23.80	17.84	383.28	381.65
125	124.20	32.61	32.20	21.24	23.16	24.94	22.67	32.28	30.11	23.14	17.14	21.87	26.56	28.94	37.30	28.81	27.75	30.50	20.25	23.83	19.55	392.36	380.89
114	116.53	32.47	29.73	23.27	23.22	22.41	15.94	32.32	26.35	25.61	25.73	17.25	19.10	25.47	25.86	22.68	33.66	25.36	27.71	17.49	19.54	360.86	363.37
103	95.86	25.64	29.26	21.67	14.89	22.15	20.41	18.65	24.05	22.01	13.83	23.12	16.78	21.30	20.57	12.75	25.15	25.12	17.83	17.54	15.10	305.81	293.73
94	93.10	27.16	26.26	20.12	19.19	21.63	22.22	22.76	25.00	24.57	17.37	23.28	20.29	22.60	24.46	22.10	26.71	23.08	21.90	25.15	19.66	325.55	316.16
85	78.25	25.60	25.17	18.50	15.05	21.06	16.18	26.77	19.72	14.96	13.34	15.72	15.82	26.24	16.60	18.54	17.90	23.33	19.07	21.28	13.36	290.25	250.46
77	73.40	22.42	26.41	15.08	14.54	21.87	16.72	20.16	20.75	18.24	14.58	17.56	14.52	20.65	24.92	18.49	24.60	20.50	17.33	16.99	14.33	265.36	262.10
70	67.86	19.61	18.85	13.81	12.34	17.57	15.78	19.12	19.75	14.31	10.61	14.64	13.69	23.05	25.26	17.98	20.29	19.24	14.44	17.22	15.28	244.41	234.15
64	58.33	17.90	18.20	15.64	16.09	15.01	16.68	15.83	17.57	13.07	12.25	15.94	19.32	16.71	17.37	11.95	21.97	15.29	18.95	14.79	19.54	210.46	236.27

Notes: * Thinning was carried out at 14% intensity in July 1997 (9 years after planting - 7th year of harvesting).
* Thinned densities are 0.86 of the corresponding unthinned density.

TABLE 6. EXPERIMENT 3 - DISCOUNTED CASH FLOW ANALYSIS UP TO THE 18TH YEAR OF PLANTING ON VARIOUS PLANTING DENSITY OPTIONS IN OIL PALMS PLANTED ON A COASTAL SOIL

		FFB price (RM t^{-1})				
		160	200	240	280	320
Density (palm ha^{-1})	Thinning intensity and period	Net present values @ 10% discount rate (RM ha^{-1})				
299	No thinning	-10 119	-5 164	-208	4 748	9 703
271	No thinning	-9 049	-4 155	739	5 633	10 526
246	No thinning	-5 334	403	6 139	11 875	17 611
223	No thinning	-5 291	123	5 536	10 950	16 364
203	No thinning	-1 790	4 469	10 728	16 987	23 246
184	No thinning	-178	6 327	12 833	19 338	25 843
167	No thinning	-553	5 582	11 717	17 851	23 986
152	No thinning	-1 642	3 919	9 480	15 041	20 602
138	No thinning	-62	5,807	11 677	17 546	23 416
125	No thinning	<u>510</u>	6 375	12 240	18 106	23 971
114	No thinning	-138	5 356	10 850	16 344	21 838
103	No thinning	-2 386	2 216	6 818	11 419	16 021
94	No thinning	-1 544	3 200	7 943	12 687	17 430
85	No thinning	-2 843	1 347	5 536	9 726	13 915
77	No thinning	-3 531	318	4 167	8 015	11 864
70	No thinning	-4 230	-711	2 808	6 327	9 846
64	No thinning	-5 335	-2 263	808	3 880	6 952
299	14% at year 9	-9 888	-4 973	-57	4 858	9 773
271	14% at year 9	-7 158	-1 754	3 650	9 054	14 459
246	14% at year 9	-5 994	-567	4 861	10 289	15 717
223	14% at year 9	-2 891	3 218	9 326	15 435	21 543
203	14% at year 9	-3 304	2 386	8 076	13 766	19 456
184	14% at year 9	281	<u>6 865</u>	<u>13 448</u>	<u>20 031</u>	<u>26 614</u>
167	14% at year 9	27	6 287	12 547	18 807	25 067
152	14% at year 9	-71	5 943	11 957	17 970	23 984
138	14% at year 9	-85	5 725	11 535	17 345	23 155
125	14% at year 9	351	6 116	11 880	17 644	23 408
114	14% at year 9	-188	5 245	10 678	16 111	21 545
103	14% at year 9	-2 690	1 774	6 238	10 702	15 166
94	14% at year 9	-1 737	2 908	7 553	12 198	16 843
85	14% at year 9	-4 046	-281	3 485	7 250	11 015
77	14% at year 9	-3 530	289	4 108	7 927	11 746
70	14% at year 9	-4 498	-1 094	2 310	5 714	9 119
64	14% at year 9	-4 520	-1 208	2 105	5 417	8 729

Notes: * Highest NPV's underlined.
* Triangular plantings.

TABLE 7. EXPERIMENT 4 - THE EFFECTS OF PLANTING DENSITY AND THINNING ON FRESH FRUIT BUNCH (FFB) YIELDS DURING THE FIRST 16 YEARS OF PRODUCTION IN OIL PALMS PLANTED ON A COASTAL SOIL

	FFB yields (kg palm^{-1})																						
Density		YR 7		YR 8		YR 9		YR 10		YR 11		YR 12		YR 13		YR 14		YR 15		YR 16		YR 1 - 16	
(palms ha^{-1})	YR 1 - 6	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin
337	321.38	54.33	27.63	29.7	40.22	47.1	69.92	31.73	45.19	34.7	73.86	26.71	57.52	24.05	113.58	13.93	34.25	39.72	108.28	43.32	50.22	666.67	942.05
288	411.65	58.59	56.4	43.75	79.17	56.15	71.81	41.91	62.78	41.81	88.97	35.17	68.36	22.53	133.88	23.74	48.5	54.96	123.83	61.2	124.61	851.46	1 269.96
246	483.68	79.74	93.7	59.58	52.83	56.56	113.36	54.94	119.58	58.72	95.79	50.96	130.21	35.45	145.08	32.6	76.69	79.35	136.42	90.35	110.56	1 081.93	1 557.90
210	560.14	108.43	128.92	80.49	81.86	87.47	124.03	86.99	81.64	59.5	125.56	70.72	126.72	46.33	197.37	52.97	69.08	103.99	239.44	117.67	177.61	1 374.70	1 912.37
180	677.52	153.1	141.77	103.01	87.14	96.37	136.28	102.4	127.72	94.32	130.51	89.01	119.62	88.24	177.49	86.89	91.32	135.29	204.72	99.78	179.69	1 725.93	2 073.78
153	751.40	171.9	143.83	125.67	103.64	133.05	170.08	137.45	130.44	130.15	108.22	132.39	130.3	77.02	211.26	91.23	91.58	202.98	263.78	165.83	183.03	2 119.07	2 287.56
131	881.06	215.71	197.31	176.82	186.64	168.2	183	165.37	163.56	152.77	208.49	165.87	216.52	117.03	266.23	157.52	176.77	221.1	264.78	192.47	276.53	2 613.92	3 020.89
112	875.43	221.34	219.46	163.27	121.06	208.51	223.61	198.61	135.86	156.76	224.19	178.32	180.67	114.09	235.67	188.57	161.8	257.21	270.61	207.65	280.42	2 769.76	2 928.78
96	809.63	231.35	198.25	179.52	194.08	211.85	202.69	205.74	162.14	190.9	127.07	192.47	200.48	141.18	284.99	192.82	187.64	253.55	232.75	240.72	225.47	2 849.73	2 825.19
82	850.61	280.26	235.74	213.46	150.39	222.68	157.72	214.82	171.06	211.27	186.93	234.22	173.76	160.35	265.69	241.25	191.17	298.55	285.64	249.85	274.14	3 177.32	2 942.85
70	848.10	254.78	207.5	203.55	158.83	218.09	210.61	244.99	116.03	190.91	179.66	283.05	181.18	135.88	291.64	303.41	177.16	325.97	307.39	295.41	287.81	3 304.14	2 965.91

	FFB yields (t ha^{-1})																						
Density		YR 7		YR 8		YR 9		YR 10		YR 11		YR 12		YR 13		YR 14		YR 15		YR 16		YR 1 - 16	
(palms ha^{-1})	YR 1 - 6	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin	Unthin	Thin
337	108.31	18.31	7.91	10.01	10.18	15.87	17.69	10.69	11.43	11.69	18.69	9.00	14.55	24.69	28.74	4.69	11.54	13.39	27.39	14.57	12.71	241.21	269.14
288	118.55	16.87	14.70	12.60	17.10	16.17	15.51	12.07	13.56	12.04	19.22	10.13	14.76	21.08	28.92	6.84	13.97	15.83	26.75	17.42	26.92	259.60	309.96
246	118.97	19.62	19.77	14.66	9.77	13.91	20.97	13.52	22.12	14.45	17.72	12.54	24.09	24.20	26.84	8.02	18.87	19.52	25.24	22.23	20.45	281.63	324.81
210	117.62	22.77	23.17	16.90	12.93	18.37	19.60	18.27	12.90	12.49	19.84	14.85	20.02	27.47	31.18	11.12	14.51	21.84	37.83	24.60	28.06	306.30	337.66
180	121.95	27.56	22.31	18.54	11.76	17.35	18.40	18.43	17.24	16.98	17.62	16.02	16.15	25.14	23.96	15.64	16.49	24.35	27.64	17.84	24.26	319.80	317.78
153	114.96	26.30	20.56	19.23	11.92	20.36	19.56	21.03	15.00	19.91	12.44	20.26	14.98	23.26	24.29	13.96	14.01	31.06	30.33	25.48	21.05	335.80	299.10
131	115.42	28.26	22.64	23.16	18.29	22.03	17.93	21.66	16.03	20.01	20.43	21.73	21.22	31.16	26.09	20.64	23.16	28.96	25.95	25.13	27.10	358.15	334.26
112	98.05	24.79	21.00	18.29	10.17	23.35	18.78	22.24	11.41	17.56	18.83	19.97	15.18	27.00	19.80	21.12	18.12	28.81	22.73	23.45	23.56	324.63	277.63
96	77.73	22.21	17.00	17.23	13.97	20.34	14.59	19.75	11.67	18.33	9.15	18.48	14.43	26.01	20.52	18.51	18.01	24.34	16.76	23.13	16.23	286.05	230.06
82	69.75	22.98	16.68	17.50	9.32	18.26	9.78	17.62	10.61	17.32	11.59	19.21	10.77	26.57	16.47	19.78	15.68	24.48	17.71	20.23	17.00	273.69	205.36
70	59.36	17.83	12.16	14.25	8.42	15.27	11.16	17.15	6.15	13.36	9.52	19.81	9.60	23.47	15.46	21.24	12.40	22.82	16.29	20.72	15.25	245.27	175.77

Notes: * Thinning was carried out at 25% intensity in July 1997 (9 years after planting - 7th year of harvesting).
* Thinned densities are 0.75 of the corresponding unthinned density.

TABLE 8. EXPERIMENT 4 - DISCOUNTED CASH FLOW ANALYSIS UP TO THE 18TH YEAR OF PLANTING ON VARIOUS PLANTING DENSITY OPTIONS IN OIL PALMS PLANTED ON A COASTAL SOIL

		FFB price (RM t^{-1})				
		160	200	240	280	320
Density (palm ha^{-1})	Thinning intensity and period	Net present values @ 10% discount rate (RM ha^{-1})				
337	No thinning	-13 326	-9 223	-5 119	-1 016	3 088
288	No thinning	-10 388	-5 993	-1 598	2 797	7 192
246	No thinning	-8 010	-3 410	1 189	5 789	10 388
210	No thinning	-5 722	-866	3 989	8 845	13 701
180	No thinning	-3 828	1 237	6 302	11 367	16 433
153	No thinning	-2 603	2 495	7 593	12 691	17 789
131	No thinning	-937	4 405	9 746	15 088	20 429
112	No thinning	-1 942	2 816	7 573	12 330	17 087
96	No thinning	-3 358	722	4 802	8 882	12 962
82	No thinning	-3 470	384	4 238	8 092	11 945
70	No thinning	-4 445	-1 071	2 302	5 676	9 050
337	25% at year 9	-13 135	-8 835	-4 535	-235	4 065
288	25% at year 9	-9 306	-4 444	417	5 278	10 140
246	25% at year 9	-6 928	-1 881	3 166	8 213	13 260
210	25% at year 9	-5 202	-96	5 010	10 116	15 222
180	25% at year 9	-4 405	543	5 491	10 439	15 387
153	25% at year 9	-4 227	403	5 033	9 663	14 293
131	25% at year 9	-2 126	2 879	7 884	12 889	17 894
112	25% at year 9	-3 827	360	4 548	8 735	12 923
96	25% at year 9	-5 433	-1 991	1 451	4 893	8 335
82	25% at year 9	-6 040	-2 992	56	3 104	6 152
70	25% at year 9	-6 924	-4 330	-1 737	856	3 449

Notes: * Highest NPV's underlined.
* Square plantings.

TABLE 9. EXPERIMENT 5 - THE EFFECTS OF PLANTING DENSITY AND THINNING ON FRESH FRUIT BUNCH (FFB) YIELDS DURING THE FIRST 18 YEARS OF PRODUCTION IN OIL PALMS PLANTED ON AN INLAND SOIL

		FFB yields (kg palm^{-1})							
Density (palms ha^{-1})		YR 7 - 18				YR 1 - 18			
	YR 1 - 6	Unthin	Thin 1	Thin 2	Thin 3	Unthin	Thin 1	Thin 2	Thin 3
296	497	1 019	2 859	2539	1 455	1 516	3 356	3 036	1 952
268	515	1 027	2 510	2881	1 535	1 542	3 024	3 396	2 050
243	577	1 386	2 798	2788	1 734	1 963	3 375	3 365	2 311
220	663	1 489	3 692	3196	2 042	2 151	4 355	3 859	2 705
199	708	1 657	3 831	3743	2 298	2 365	4 539	4 450	3 006
181	773	1 957	3 744	3918	2 651	2 730	4 517	4 691	3 424
164	841	2 286	4 190	3919	3 079	3 126	5 030	4 760	3 920
148	819	2 607	4 066	3778	2 882	3 425	4 885	4 597	3 701
135	878	3 008	4 269	4057	3 333	3 886	5 147	4 935	4 211
122	918	3 273	4 469	4050	3 616	4 191	5 387	4 968	4 534

		FFB yields (t ha^{-1})							
Density (palms ha^{-1})		YR 7 - 18				YR 1 - 18			
	YR 1 - 6	Unthin	Thin 1	Thin 2	Thin 3	Unthin	Thin 1	Thin 2	Thin 3
296	147.19	301.57	423.07	375.78	204.56	448.76	570.26	522.97	351.75
268	137.94	275.27	336.29	386.10	204.81	413.21	474.23	524.04	342.75
243	140.21	336.68	341.37	340.16	204.51	476.89	481.58	480.37	344.72
220	145.78	327.53	406.10	351.58	225.46	473.31	551.88	497.36	371.24
199	141.67	329.72	383.14	374.25	234.49	471.39	524.81	515.92	376.16
181	140.00	354.17	340.70	356.53	233.27	494.17	480.70	496.53	373.27
164	137.91	374.83	343.54	321.34	250.38	512.74	481.45	459.25	388.29
148	121.21	385.76	300.88	279.59	226.04	506.97	422.09	400.80	347.25
135	118.49	406.11	290.31	275.89	226.36	524.60	408.80	394.38	344.85
122	112.10	399.31	272.62	247.04	222.84	511.41	384.72	359.14	334.94

Notes: * Thin 1 was carried out at 8th year after planting in November 1994.
* Thin 2 was carried out at 10th year after planting in May 1996.
* Thin 3 was carried out at 16th year after planting in January 2003.
* Thinning was at 50%; resultant densities are half the initial stand.

options, the AOD is at variable density option of 296 palms ha^{-1} thinned at eighth year after planting. Within the fixed density options, the AOD is at 135 palms ha^{-1}.

Economic analysis. The discounted cash flow analyses on the various density options up to the 20th year of planting are summarized in *Table 10*. At low FFB prices of RM 200 t^{-1} and below, the EOD is at fixed density option of 122 palms ha^{-1}. At higher prices greater than RM 200 t^{-1}, the EOD is at fixed density option of 164 palms ha^{-1}.

Compared to the fixed density options, all thinning options show a lower discounted profit. Amongst the variable density options, early thinning at year 8 appear to be most profitable at all FFB prices tested.

Experiment 6: Optimizing Variable Density Options on Coastal Soil

FFB yields. The effects of planting density and various thinning intensities on yield and yield components during the first 12 years of harvesting (14th year of planting) are summarized in *Table 11*. Yield per palm is unaffected by density during the first two years of harvesting. Interpalm competition commences at the third year of harvesting and yield per palm declines with increasing density. Whilst yield per palm declines from the third year onwards, yield per hectare continues to be highest at 185 palms ha^{-1} up to eighth year of harvesting (10th year of planting). After which, the highest yield per hectare shifts to 160 palms ha^{-1} up to 12th year of harvesting. On cumulative yield per hectare, both 185 and 160

TABLE 10. EXPERIMENT 5 - DISCOUNTED CASH FLOW ANALYSIS UP TO THE 20TH YEAR OF PLANTING ON VARIOUS PLANTING DENSITY OPTIONS IN OIL PALMS PLANTED ON AN INLAND SOIL

Density (palm ha^{-1})	Thinning intensity and period	FFB price (RM t^{-1}) 160	200	240	280	320
		Net present values @ 10% discount rate (RM ha^{-1})				
296	No thinning	-7 329	-760	5 809	12 378	18 947
268	No thinning	-6 929	-700	5 529	11 757	17 986
243	No thinning	-3 922	2 865	9 652	16 439	23 225
220	No thinning	-2 195	4 768	11 730	18 692	25 654
199	No thinning	-1 217	5 710	12 637	19 564	26 491
181	No thinning	421	7 579	14 737	21 895	29 052
164	No thinning	1 680	8 962	<u>16 244</u>	<u>23 526</u>	<u>30 807</u>
148	No thinning	1 120	7 951	14 782	21 613	28 444
135	No thinning	2 170	9 124	16 078	23 033	29 987
122	No thinning	<u>2 386</u>	<u>9,192</u>	15 998	22 804	29 609
296	50% at year 8	-3 382	4 165	11 712	19 259	26 807
268	50% at year 8	-4 394	2 497	9 388	16 280	23 171
243	50% at year 8	-2 956	4 034	11 024	18 013	25 003
220	50% at year 8	-898	6 422	13 742	21 061	28 381
199	50% at year 8	-514	6 636	13 787	20 937	28 087
181	50% at year 8	-1 379	5 280	11 940	18 599	25,258
164	50% at year 8	-1 149	5 345	11 839	18 332	24 826
148	50% at year 8	-2 612	3 222	9 056	14 890	20 723
135	50% at year 8	-2 513	3 164	8 842	14 519	20 196
122	50% at year 8	-2 765	2 676	8 117	13 557	18 998
296	50% at year 10	-5 392	1 730	8 852	15 974	23 096
268	50% at year 10	-4 264	2 799	9 862	16 924	23 987
243	50% at year 10	-3 256	3 781	10 817	17 854	24 890
220	50% at year 10	-2 320	4 693	11 707	18 720	25 733
199	50% at year 10	-1 416	5 569	12 555	19 541	26 526
181	50% at year 10	-1 180	5 635	12 450	19 264	26 079
164	50% at year 10	-1 670	4 773	11 217	17 660	24 104
148	50% at year 10	-2 978	2 819	8 617	14 415	20 212
135	50% at year 10	-2 728	2 991	8 711	14 431	20 150
122	50% at year 10	-3 699	1 536	6 771	12 006	17 241
296	50% at year 16	-8 569	-2 043	4 483	11 009	17 535
268	50% at year 16	-7 842	-1 521	4 800	11 121	17 442
243	50% at year 16	-5 628	1 030	7 688	14 346	21 004
220	50% at year 16	-3 614	3 300	10 215	17 130	24 045
199	50% at year 16	-2 655	4 251	11 157	18 063	24 969
181	50% at year 16	-395	6 134	12 664	19 193	25 722
164	50% at year 16	564	7 137	13 711	20 284	26 857
148	50% at year 16	-151	5 937	12 026	18 115	24 204
135	50% at year 16	917	7 148	13 379	19 610	25 842
122	50% at year 16	-366	6 127	12 620	19 113	25 607

Note: * Highest NPV's underlined.

TABLE 11. EXPERIMENT 6 - THE EFFECTS OF PLANTING DENSITY AND THINNING ON FRESH FRUIT BUNCH (FFB) YIELDS AND YIELD COMPONENTS DURING THE FIRST 12 YEARS OF PRODUCTION IN OIL PALMS PLANTED ON A COASTAL SOIL

Density (palm ha^{-1})	Thinning intensity and period	FFB $palm^{-1}$ (kg)												
		YR 1	YR 2	YR 3	YR 4	YR5	YR6	YR7	YR8	YR9	YR10	YR11	YR12	YR1-12
185	No thinning	41.30	91.35	131.26	173.29	197.96	128.02	155.57	123.82	115.54	133.57	172.21	155.92	1 619.81
	14% at Year 10	49.89	74.94	123.47	160.28	182.18	114.05	118.32	121.02	114.25	151.74	209.31	189.51	1 608.96
	25% at Year 10	56.44	76.81	133.81	145.90	162.47	138.86	103.15	120.19	116.94	151.53	231.68	211.17	1 648.95
	33% at Year 10	46.74	82.32	137.29	175.79	177.93	139.28	120.81	113.99	132.04	153.91	233.69	199.73	1 713.52
	Mean	48.59	81.35	131.46	163.82	180.13	130.05	124.46	119.76	119.69	147.69	211.72	189.08	1 647.81
160	No thinning	44.45	104.27	170.71	169.40	201.57	149.59	163.89	131.83	159.99	160.58	207.36	182.88	1 846.52
	14% at Year 10	38.11	84.45	146.30	170.20	192.58	137.68	133.64	117.12	144.11	166.09	209.16	208.47	1 747.91
	25% at Year 10	35.72	97.70	167.40	182.57	208.31	140.53	144.22	126.42	139.10	181.79	220.39	231.89	1 876.04
	33% at Year 10	37.61	89.22	142.50	169.04	191.41	149.93	126.78	138.34	141.34	167.24	244.74	245.32	1 843.47
	Mean	38.97	93.91	156.73	172.80	198.47	144.43	142.13	128.43	146.14	168.93	220.41	217.14	1 828.49
136	No thinning	39.04	80.55	177.09	207.95	226.60	159.65	167.74	134.27	148.64	179.54	226.24	196.29	1 943.60

Density (palm ha^{-1})	Thinning intensity and period	FFB $palm^{-1}$ (No.)												
		YR 1	YR 2	YR 3	YR 4	YR5	YR6	YR7	YR8	YR9	YR10	YR11	YR12	YR1-12
185	No thinning	14.02	16.04	16.10	16.63	15.42	9.04	9.44	6.83	6.29	7.08	8.63	7.63	133.15
	14% at Year 10	14.48	14.06	13.42	14.69	14.06	7.79	7.04	6.55	6.06	7.06	9.26	8.49	122.96
	25% at Year 10	16.35	14.58	15.13	13.98	12.35	9.29	6.30	6.49	6.53	7.57	10.11	9.55	128.23
	33% at Year 10	13.44	15.27	16.35	16.00	13.58	9.79	7.32	6.19	7.11	7.34	9.94	9.38	131.71
	Mean	14.57	14.99	15.25	15.32	13.85	8.98	7.53	6.51	6.50	7.26	9.48	8.76	129.01
160	No thinning	13.48	17.25	20.08	15.83	15.10	10.38	10.13	7.00	8.56	8.02	9.75	8.29	143.87
	14% at Year 10	12.46	16.35	17.56	16.77	15.21	10.06	8.74	6.38	7.94	8.83	10.60	10.26	141.16
	25% at Year 10	11.69	16.73	19.67	16.85	16.08	9.73	8.94	6.66	7.59	8.98	10.49	10.77	144.18
	33% at Year 10	11.98	14.13	16.27	15.00	14.63	10.27	7.77	7.27	7.60	8.02	11.10	11.42	135.46
	Mean	12.40	16.11	18.40	16.11	15.26	10.11	8.89	6.83	7.92	8.46	10.49	10.18	141.17
136	No thinning	12.51	14.60	18.72	17.98	16.91	10.98	10.30	7.23	8.19	9.26	10.70	9.19	146.57

Density (palm ha^{-1})	Thinning intensity and period	Av. b. wt. (kg)											
		YR 1	YR 2	YR 3	YR 4	YR5	YR6	YR7	YR8	YR9	YR10	YR11	YR12
185	No thinning	2.95	5.69	8.15	10.42	12.84	14.16	16.48	18.12	18.36	18.86	19.97	20.45
	14% at Year 10	3.45	5.33	9.20	10.91	12.96	14.64	16.80	18.47	18.84	21.48	22.62	22.32
	25% at Year 10	3.45	5.27	8.85	10.44	13.15	14.95	16.38	18.52	17.90	20.01	22.92	22.10
	33% at Year 10	3.48	5.39	8.39	10.99	13.10	14.22	16.51	18.41	18.58	20.97	23.52	21.29
	Mean	3.33	5.42	8.65	10.69	13.01	14.49	16.54	18.38	18.42	20.33	22.26	21.54
160	No thinning	3.30	6.04	8.50	10.70	13.35	14.42	16.19	18.83	18.69	20.02	21.27	22.06
	14% at Year 10	3.06	5.16	8.33	10.15	12.66	13.68	15.28	18.35	18.16	18.81	19.74	20.33
	25% at Year 10	3.06	5.84	8.51	10.83	12.95	14.44	16.14	18.98	18.92	20.25	21.01	21.54
	33% at Year 10	3.14	6.32	8.76	11.27	13.09	14.60	16.32	19.03	18.59	20.85	22.04	21.49
	Mean	3.14	5.84	8.52	10.74	13.01	14.29	15.98	18.80	18.59	19.98	21.02	21.36
136	No thinning	3.12	5.52	9.46	11.57	13.40	14.54	16.29	18.56	18.15	19.40	21.14	21.36

Density (palm ha^{-1})	Thinning intensity and period	FFB ha^{-1} (t)												
		YR 1	YR 2	YR 3	YR 4	YR5	YR6	YR7	YR8	YR9	YR10	YR11	YR12	YR1-12
185	No thinning	7.64	16.90	24.28	32.06	36.62	23.68	28.78	22.91	21.37	24.71	31.86	28.84	299.65
	14% at Year 10	9.23	13.86	22.84	29.65	33.70	21.10	21.89	22.39	18.17	24.13	33.28	30.13	280.37
	25% at Year 10	10.44	14.21	24.75	26.99	30.06	25.69	19.08	22.24	16.25	21.06	32.20	29.35	272.32
	33% at Year 10	8.65	15.23	25.40	32.52	32.92	25.77	22.35	21.09	16.37	19.08	28.74	24.57	272.69
	Mean	8.99	15.05	24.32	30.31	33.33	24.06	23.02	22.16	18.04	22.25	31.52	28.22	281.26
160	No thinning	7.11	16.68	27.31	27.10	32.25	23.93	26.22	21.09	25.60	25.69	33.18	29.26	295.45
	14% at Year 10	6.10	13.51	23.41	27.23	30.81	22.03	21.38	18.74	19.89	22.92	28.86	28.77	263.65
	25% at Year 10	5.72	15.63	26.78	29.21	33.33	22.48	23.08	20.23	16.69	21.81	26.45	27.83	269.24
	33% at Year 10	6.02	14.28	22.80	27.05	30.63	23.99	20.28	22.13	15.12	17.89	26.19	26.25	252.61
	Mean	6.24	15.03	25.08	27.65	31.75	23.11	22.74	20.55	19.32	22.08	28.67	28.03	270.24
136	No thinning	5.31	10.95	24.08	28.28	30.82	21.71	22.81	18.26	20.22	24.42	30.77	26.70	264.33

Note: * First period of thinning was carried out at 10^{th} year after planting (8^{th} year of harvesting).

palms ha^{-1} recorded comparable yield, 13% higher than yield at 136 palms ha^{-1}.

The effect of interpalm competition is also evident on bunch number per palm from the third year of harvesting with a decrease in bunch number with density. The effect on bunch weight is less severe. At the 14th year of planting, the differential is 20% and 4% for bunch number and weight respectively between 136 and 185 palms ha^{-1}.

Thinning at various intensities was carried out at eighth year of harvesting (10th year of planting) at both 185 and 160 palms ha^{-1}. Yield per palms improves from the second year after thinning in all the thinning treatments. Yield improvement is due to both higher bunch number and bunch weight at 185 palms ha^{-1}, whilst the improvement at 160 palms ha^{-1} is mainly due to higher bunch number.

On yield per hectare, yield improves with thinning intensity up 25% at 185 palms ha^{-1} with the 14% thinning recording a higher yield improvement. Improvement in yield per palm at 160 palms ha^{-1} after thinning does not result in improvement in yield per hectare. On cumulative yields up to the 14th year of planting, the AOD is at fixed density option of 185 palms ha^{-1}.

Economic analysis. Based on results up to 14th year of planting, discounted cash flow analysis at various prices of FFB was carried out and the results are summarized in *Table 12*. At FFB prices below RM 280 t^{-1}, the fixed density option of 160 palms ha^{-1} gave the highest returns. At FFB prices greater than RM 320 t^{-1}, the EOD shifted to a higher fixed density option of 185 palms ha^{-1}.

With respect to the variable density options, thinning at 10th year of planting may be too early because yield per hectare at the unthinned 160 and 185 palms ha^{-1} are still sustainable at 14th year of planting. Comparing the differences in NPV and the fact that yields will continue to decline in subsequent years at 160 and 185 palms ha^{-1}, there is a strong possibility that the EOD may shift to the variable density option with a later thinning period. Based on the results to date, the variable density options appear promising. Whether the fixed high density option or the variable density option is better can only be confirmed at a later stage of the experiments but both options appear to be better than the fixed conventional planting density.

CONCLUSION

Based on results to date from this project, the optimum planting density as a fixed option remains at 136 – 148 palms ha^{-1} on conventional planting cycle of 20 – 25 years in the west Malaysian environment. Hence, there is no change to the reported conclusions in the earlier trials (Corley *et al*., 1973; Tan and Ng, 1977; Goh, 1982).

However, if one opts for a shorter replanting cycle of 15-20 years, the optimum shifts to a higher density of 185 palms ha^{-1}. Previous experiments did not consider higher density options on a shorter planting cycle, though Corley *et al*. (1973), did suggest the possibility of high density planting on a 15-year cycle. More recently, Donough and Kwan (1991) showed it was possible to adopt a 20-year planting

TABLE 12. EXPERIMENT 6 - DISCOUNTED CASH FLOW ANALYSIS UP TO THE 14TH YEAR OF PLANTING ON VARIOUS PLANTING DENSITY OPTIONS IN OIL PALMS PLANTED ON A COASTAL SOIL

		FFB price (RM t^{-1})				
		160	200	240	280	320
Density (palm ha^{-1})	Thinning intensity and period	Net present values @ 10% discount rate (RM ha^{-1})				
185	No thinning	-759	4 581	9 922	15 263	<u>20 604</u>
	14% at year 10	-1 853	3 107	8 067	13 028	17 988
	25% at year 10	-2 078	2 790	7 657	12 525	17 392
	33% at year 10	-1 729	3 238	8 204	13 171	18 137
160	No thinning	<u>-315</u>	<u>4 902</u>	<u>10 120</u>	<u>15 337</u>	20 554
	14% at year 10	-2 018	2 634	7 286	11 939	16 591
	25% at year 10	-1 407	3 436	8 278	13 120	17 962
	33% at year 10	-2 336	2 194	6 723	11 253	15 783
136	No thinning	-3 093	1 489	6 071	10 652	15 234

Note: * Highest NPV's underlined.

cycloe with planting densities of 180 – 190 palms ha^{-1} and still obtain better discounted profits than that from 143 palms ha^{-1} on a 25-year cycle. As the oil palm improvement cycle is about 12 years, a shorter replanting cycle will allow a faster utilization of the improved varieties. Similarly, elite planting materials produced through cloning will also be quickly utilized. The high density planting recommended are for current planting materials. With ongoing breeding programme emphasizing higher bunch index and a slower height increment, palms will be more compact and density can be further increased to raise the yield potential. PORIM PS1 series and ASD compact palms (Escobar and Alvarado, 2003) are examples of the newer materials that can be planted at high density planting. Breure and Corley (1983) and Corley and Donough (1992) showed that palms with smaller leaf area have higher optimum densities.

In high *Ganoderma* infested areas, high density planting will sustain yields in the later mature phase when disease reduces the stand (Nazeeb *et al*., 2000). As the industry embarks into the third cycle of replanting, disease incidence is expected to commence earlier and losses in stand at much faster rates. High density planting will sustain higher stand than conventional stand at equivalent planting cycle. Moreover even if losses are great at high density planting, replanting can be carried out sooner than with conventional planting density with still better economic returns.

Whilst more data is required from the variable density experiments to confirm optimal starting densities and thinning period, results to date, show that the concept is economically viable contrary to earlier suggestions by Corley *et al*. (1973) and Hartley (1977). The variable density options favour triangular spacing as starting patterns. Results suggest it is financially more profitable if the yield optimization through systematic spacing is achieved in the pre-thinning stage than in the post. In terms of utilization of space, thinning square plantings by 50% maintains the systematic but it is less efficient compared to the equilateral triangular in the pre-thinning stage which has a greater influence on cash flow. Whilst it is more efficient in terms of utilization of space at the post thin period, the high thinning intensity reduces yield per unit area resulting in lower yields. Similarly with hexagonal spacing, too much yield is sacrificed in the pre-thin and too many palms in the post thin stage as thinning is also by 50%.

Hence, the initial recommendations for variable density option is to plant at 180 – 200 palms ha^{-1} at triangular spacing and thin at the 12^{th} – 14^{th} year of planting at 14% or 25%. As the experiments on variable density options are ongoing, recommendations will be reviewed accordingly.

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Appendix 1

Cost Assumptions in NPV Analysis

Expenditure

	Coastal	Inland		
a) Immature				
1) Land preparation	RM 2200 ha^{-1}	Terrace planting Straight-line	RM 2400 ha^{-1} RM 1900 ha^{-1}	
2) Planting material	RM 5.25 $palm^{-1}$	-	RM 5.25 $palm^{-1}$	
3) Cover establishment	RM 600 ha^{-1}	Terrace planting Straight-line	RM 700 ha^{-1} RM 550 ha^{-1}	
4) Upkeep	RM 520 ha^{-1} yr^{-1}		RM 600 ha^{-1} yr^{-1}	
5) Manuring	RM 2.16 $palm^{-1}$ (Yr 1) RM 5.05 $palm^{-1}$ (Yr 2) RM 2.07 $palm^{-1}$ (Yr 3)	- - -	RM 2.66 $palm^{-1}$ (Yr 1) RM 6.35 $palm^{-1}$ (Yr 2) RM 2.41 $palm^{-1}$ (Yr 3)	
b) Mature				
1) Upkeep	RM 320 ha^{-1}		RM 320 ha^{-1}	
2) Manuring	RM 3.07 $palm^{-1}$ (Yr 3 only) RM 4.60 $palm^{-1}$ or as per treatment rates		RM 3.20 $palm^{-1}$ (Yr 3 only) RM 4.80 $palm^{-1}$ or as per treatment rates	
3) Fertilizer prices	Urea AS MOP RP Kieserite	RM 1030 t^{-1} RM 440 t^{-1} RM 760 t^{-1} RM 291 t^{-1} RM 460 t^{-1}	- AS MOP RP Kieserite	 RM 440 t^{-1} RM 760 t^{-1} RM 291 t^{-1} RM 460 t^{-1}
4) Harvesting & collection	RM 37 t^{-1} FFB	-	RM 37 t^{-1} FFB	
c) Overhead	RM 778 ha^{-1}	-	RM 778 ha^{-1}	