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SELECTION OF OIL PALMS FOR HIGH DENSITY PLANTING

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SUMMARY

Three oil palm (*Elaeis guineensis* JACQ.) experiments in West New Britain, Papua New Guinea, are discussed. The extent of heritable variation in growth parameters is estimated from parent-offspring correlations and from repeatabilities of successive measurements on the same palms. Heritability of vegetative measurements appears high. For yield of fruit, and growth parameters derived therefrom, the heritability is lower, but repeatabilities are improved when yield is averaged over three-year periods.

In the early years of a planting density trial, when the level of interpalm competition was low, individual palms were selected on the basis of yield of fruit per palm and various growth parameters. The performance of the selected palms was then examined in later years, under more intense competition, to assess the possibilities of selection for high planting density. Indications are that selection for high bunch index (the proportion of total dry matter used for bunch production) would be more effective than selection for yield in giving palms capable of yielding well at high density. Selection for high leaf area ratio or for short leaf rachises was not effective.

INTRODUCTION

The primary objective of oil palm breeding should be to maximise the yield of oil per hectare. However, most breeding in the past has concentrated on yield per palm, neglecting the important aspect of planting density. Ideally, in the selection of individual palms, whether for crossing to produce seed or as ortets for vegetative propagation, one should take into account not only the yield per palm but also the expected optimum planting density for the progeny or clone be produced. However, it is not obvious how planting density can be taken into account in the selection of individual palms.

SPARNAAIJ (1969) suggested a system of 'four-row planting', in which every 5th row of palms was omitted. Each progeny was planted across all four rows, thus allowing performance under a normal level of interpalm competition to be assessed in the inner rows, and performance under a reduced level of competition in the outer rows. From the difference it was hoped to estimate spacing requirements for each progeny, but OBASOLA (1970) reported that, in practice, the outer rows yielded less than the inner

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rows. This was perhaps due to competition from the dense ground cover which developed in the spaces.

HARDON et al., (1972) considered that palms with a high 'bunch index' might be particularly suited to high density planting. The bunch index is the proportion of total dry matter used for fruit bunch production; multiplication by the ratio of oil to bunch weight gives the harvest index of DONALD (1962). The suggestion of HARDON et al. (1972) was based on the fact that palms selected for high bunch index were vegetatively less vigorous than the population mean, with smaller leaf area and shorter trunks, and thus tended to be overshaded by their neighbours. Despite this, the yield of such palms was above average, indicating tolerance to competition. HIRSCH (1989) emphasised the importance of over-shading by neighbouring palms in progeny trials; when progeny means were examined, a negative correlation between height and yield was found, but for individual palms within progenies, the correlation was positive. In other words, individuals benefit from overshading their neighbours within a plot of the same progeny, even in a trial where the shorter progenies were the higher yielding.

CORLEY (1973) showed that maximum dry matter production from oil palm is obtained at high leaf area indices with planting densities considerably higher than are normally used commercially. At such high planting densities, the bunch index is very low, and yield of fruit is consequently lower than at normal densities. To make best use of available environmental resources, there would be advantage in selecting palms which, when planted at densities that maximise dry matter production, remain capable of diverting a large proportion of dry matter to bunch production. The possibilities of producing specific palm types to meet such requirements are increased now that it is possible to produce genetically uniform material by vegetative propagation using tissue culture (JONES, 1974; RABECHAULT & MARTIN, 1976; CORLEY et al., 1981; AHEE et al., 1981; PANNETIER et al., 1981). So far, though, the proposal that high bunch index palms might be suited to high density planting has not been tested, as no data is yet available from properly designed progeny × density or clone × density experiments.

Because the partitioning of dry matter to reproductive and vegetative growth varies with the level of interpalm competition, CORLEY (1976) suggested that potential bunch index would best be assessed at a low planting density, with minimal interpalm competition. Attempts could then be made to estimate the optimum planting density for progenies or clones from vegetative measurements, in particular mean leaf area.

In this paper we present some evidence from a spacing trial that selection for high bunch index, under a low level of interpalm competition, does indeed give material able to yield well at high planting densities.

We also give some estimates of heritabilities of growth parameters from oil palm trials in West New Britain. Selection progress will be greatest where the characters selected for are highly heritable. HARDON (1976) has pointed out that the number of parents that can be handled in a single experiment with a tree crop is far below the minimum numbers suggested by other authors for the estimation of heritabilities. However, from repeated experiments a general pattern of the level of genetic control for different characters may become apparent. HARDON et al. (1972), TAN (1978) and OOI (1978) have estimated heritabilities of growth parameters for oil palm in Malaysia, and their results are compared with ours in this paper.

MATERIALS AND METHODS

The experiments described in this paper were all planted on young volcanic soils at Dami Oil Palm Research Station, West New Britain, Papua New Guinea.

Experiment 1. This trial includes 15 dura × pisifera crosses planted in 1969 in a randomised block design with 5 replications and 16 palms/plot at a density of 143 palms/ha. Dura (D) and pisifera (P) are the thick shelled and shell-less fruit type respectively, which when crossed give the thin shelled tenera (T) hybrid, normally planted commercially. The dura female parents were selected from two progenies of a population generally referred to as Deli dura (HARDON & THOMAS, 1968). The pisifera male parents came from a tenera × pisifera cross planted in Malaysia and coded BM 119. This progeny originates from a palm known as SP 540, from AVROS (now RISPA) in Medan (HARTLEY, 1977).

Experiment 2. This was a density × fertiliser trial planted in October 1970 with tenera material of the same parentage as that in Experiment 1. Four densities were compared, 56, 110, 148 and 186 palms/ha; for all but the lowest, each plot was divided into four sub-plots for four different levels of fertilisers. The experiment was discussed in detail by BREURE (1977).

Experiment 3. This experiment includes 56 dura × pisifera progenies, planted in a split-plot design with pisifera parents determining main plots of 16 palms and the dura parents determining sub-plots of four palms each. The experiment was planted in 1976, with 3 replications at 116 palms/ha and 3 at 143 palms/ha. Different densities are not taken into account for results used in this paper, as the palms were too young for density effects to be apparent. The parents of the progenies in experiment three were from two further trials, experiments 4 and 5.

Experiment 4. The female parents for experiment 3 were selected from this trial, planted in 1968, and originating from the same population as the dura parents of experiment 1. ROSENQUIST (1981) discusses experiment 4 in more detail, and comments that despite the very restricted origin of the material there were significant differences between progenies.

Experiment 5. The pisifera male parents for experiment 3 were selected from two families in this trial, DM 742 and DM 743. DM 742 was derived from the family BM 119 (see experiment 1), while the parents of DM 743 were from BM 119 and BM 29. The latter was a tenera progeny, one of whose parents was the well known 'Dumpy' palm, E 206 (HARTLEY, 1977). Six pisiferas from each family were each crossed with four duras selected from within experiment 4.

Observations. Growth parameters were estimated from non-destructive measurements, as developed by HARDON et al. (1969) and CORLEY et al. (1971). In experiments 1, 4 and 5 the measurements were done in 1974 and 1975, with the exception of rachis length which was measured only in 1974. Yield data were for the period September 1972 to March 1975. Trunk diameter was measured at the level of leaf 64 (counting downwards from the youngest fully open leaf) in September 1975.

In experiment 3 the first fully open leaves were measured on three occasions between April 1979 and March 1981. Yield data were averaged from June 1980 to September 1981, height increment was measured from 1980 to 1981, and trunk diameter was measured at the level of leaf 56 in August 1980.

In experiment 2, leaf measurements, height and annual leaf production were recorded regularly from 1975 to 1980. From the measurements, the total dry matter production per palm (TDMP), net assimilation rate (NAR), leaf area index (LAI), dry matter used in vegetative growth (VDM), and bunch index (BI) were estimated as described by CORLEY et al. (1971).

Heritabilities of growth parameters were estimated from the individual parental measurements in experiments 4 and 5, and the progeny means in experiment 3. As the two generations were recorded at different stages of maturity, estimating heritability by conventional offspring parent regression of the actual values (LUSH, 1940) is not satisfactory, since any change in environmental factors which tended to alter the range of phenotypic variation of the progenies could alter the estimated heritability obtained. This problem can be overcome by calculating the heritability from data coded in terms of standard deviation units (FREY & HORNER, 1957). FREY & HORNER state, and it can be shown mathematically, that such a regression is identical to a correlation coefficient calculated from the original data. In this paper, the so-called heritability in standard units is therefore obtained from simple correlation coefficients between the original values of growth parameters. Heritabilities were estimated separately for the families DM 742 and DM 743, because of their distinct genetic origins.

The repeatability, or intra-class correlation, calculated from repeated measurements on the same palms, is related to heritability, but tends to overestimate it (FALCONER, 1961). Repeatabilities were calculated from the growth measurements in individual years in experiment 1, and in the 110/ha treatment of experiment 2. Because leaf size and rate of leaf production were changing from year to year during the recording period, the 'between year' component of variation was removed before estimating repeatability.

Yield of oil palms varies considerably from year to year, and single year's data are not generally considered reliable. For this reason, repeatabilities for those parameters which require yield data for their calculation were also estimated from data for three consecutive three-year periods, for individual palms in experiment 2.

Selection. Within experiment 2, palms were selected from each plot of the treatments at 148 and 185 palms/ha, based on data for the second and third years of production. The numbers of palms/plot were different at the two densities, and in order to give roughly comparable selection intensities one palm/plot was selected from those plots at 148/ha, and two per plot from those at 186/ha. This gave selection intensities of 8% and 10% respectively. A number of selection criteria were used, and mean values of yield, and other growth parameters, for the selected palms were compared with the treatment means to test the effect of selection.

Table 1. Estimates of heritability from offspring × parent correlations, and repeatabilities.

	Offspring × parent correlations		Repeatabilities		
	family	family	progeny means	individual palms	
	DM 742	DM 743	Expt 1	Expt 1	Expt 2
Leaf production[1]	053**	−0.34	0.82	0.72	0.53
Leaf area[1]	0.85**	0.69**	0.82	0.70	0.74
Petiole cross-section[1]	0.72**	0.21	0.87	0.86	0.77
Rachis length[1]	0.61**	0.44*	0.92	0.69	0.64
Height increment[1]	0.52*	0.04	0.68	0.43	0.39
Vegetative DMP[1]	0.63**	0.21	0.88	0.81	0.84
Leaf area ratio[1]	0.68**	0.66**	0.81	0.54	0.67
Yield of fruit[2]	−0.10	0.47**	0.23	0.14	0.12
Total DMP[2]	0.65**	0.53**	0.48	0.35	0.29
Bunch Index[2]	0.33	0.34	0.57	0.22	0.19
Net assimilation rate[2]	0.55**	0.32	0.41	0.19	0.30

[1] Offspring × mid-parent correlations.
[2] Offspring × female-parent correlations.

Table 2. Comparison of repeatabilities for yield and other characters based on single years and on means for three-year periods (Experiment 2).

	Single years	Three-year periods
Yield of fruit	0.12	0.27
Total dry matter production	0.29	0.55
Bunch index	0.19	0.45
Net assimilation rate	0.30	0.72

RESULTS

Heritabilities. Estimates of heritability from offspring-parent correlations, and from repeatabilities, are given in Table 1. In Table 2 repeatabilities for yield, and for other parameters requiring yield for their calculation, are compared for single years and for 3-year periods.

Selection and plant density. In Table 3, yields per palm and leaf area indices for palms planted at 148 and 186 per ha are compared with those at 56 per ha, to give an indication of the level of interpalm competition at different ages.

The effects of selection for high early yield, and for various other parameters, are shown in Table 4, where the mean values for yield and growth parameters of selected palms are compared with the overall means for the corresponding density treatment.

Table 3. Yields per palm and leaf area indices at various densities (Experiment 2).

	Years 2–3		Years 4–7	
	yield*	LAI	yield*	LAI
56 palms/ha	100	1.6	100	2.1
148 palms/ha	89	3.6	59	5.5
186 palms/ha	72	4.5	38	6.7

* Expressed as a percentage of that at 56/ha.

Table 4. Effect of selection in years 2 and 3 on yield and other characters in later years.

Selected in year 2 and 3	Yield per palm (kg)		Growth parameters (years 1–5)					
for:	yr 4–8½	yr 1–8½	VDM kg/palm	BI %	LAR m²/kg	LA m²	Ht(1978) cm	RL cm
	148 palms/ha (selection intensity 8%)							
High yield	876	1442	116	47	2.04	8.8	405	562
High BI	923	1491	103	51	2.10	8.2	393	558
High LAR	775	1307	98	48	2.37	8.4	362	541
High NAR	895	1434	116	44	1.99	7.9	415	556
Low VDM	785	1278	96	48	2.22	6.6	376	530
Low RL	731	1222	107	44	2.18	7.7	401	518
Mean of all palms	797	1314	111	46	2.07	8.5	391	554
	186 palms/ha (selection intensity 10%)							
High yield	545	1060	118	39	2.00	8.8	425	588
High BI	589	1064	105	42	2.07	8.3	404	574
High LAR	463	921	98	40	2.25	8.5	371	568
High NAR	557	1007	123	37	1.70	7.6	452	576
Low VDM	428	865	94	39	2.14	7.8	371	556
Low RL	476	896	113	36	1.94	7.8	426	540
Mean of all palms	484	918	110	38	1.98	8.3	411	575

DISCUSSION

Heritabilities. Considering first the offspring × mid-parent correlations, Table 1 shows that significant correlations were obtained, for offspring derived from both groups of male parents, for leaf area, rachis length, leaf area ratio, and total dry matter production. For the DM 742 male parents, but not for DM 743, the values for petiole cross-section, leaf production, height increment and vegetative dry matter production were also significant.

Pisifera palms commonly fail to set fruit, so for those parameters involving fruit yield in their calculation, offspring × female parent correlations were calculated. Table 1 shows significant correlations, for at least one of the two groups, for fruit

Table 5. Heritabilities estimated from variances within and between progenies.

Authors*	1	1	1	2	3
Population	D × T	D × P	D × P	D × D	D × P
	Narrow sense heritabilities				
Leaf area	–	1.07	–	na	0.13
Rachis length	na	na	na	na	0.81
Vegetative DMP	–	0.65	0.41	–	0.24
Leaf area ratio	–	–	0.32	–	0.83
Yield of fruit	0.23	0.33	0.54	0.36	0.08
Total DMP	–	0.56	–	–	0.06
Bunch index	0.48	–	0.55	0.33	0.20
Net assimilation rate	0.34	0.27	0.17	–	0.21
	Broad sense heritabilities				
Leaf area	–	0.62	0.26	0.49	
Vegetative DMP	0.29	0.39	0.46	0.34	
Leaf area ratio	0.47	0.11	0.24	0.66	
Yield of fruit	0.18	0.44	0.35	0.36	
Total DMP	0.10	0.44	0.28	–	
Bunch index	0.51	0.46	0.40	0.33	
Net assimilation rate	0.23	0.43	0.08	0.44	

* 1: HARDON et al., 1972; 2: OOI, 1978; 3: TAN, 1978.

yield, total dry matter production and net assimilation rate. For bunch index, the correlations were positive, but not significant.

Repeatabilties based on progeny means were high for all vegetative characters in experiment 1. When based on individual palms, the repeatabilties were lower, as would be expected, but still reasonable for most characters. The repeatability of yield was very low, whether based on progeny means or on individual palms, and other characters which involved yield (total dry matter production, net assimilation rate and bunch index) had lower repeatabilities than those based on vegetative measurements alone.

The repeatabilities estimated from individual palms in experiment 2 followed a very similar pattern to those from experiment 1. Table 2 shows that the low values for yield and related characters could be increased somewhat by using average yield over successive periods of three years, rather than data for single years.

Heritabilities of growth parameters have also been estimated from covariance between relatives within experiments, by other authors (HARDON et al., 1972; TAN, 1978; OOI, 1978), and their results are summarised in Table 5. OOI's results were for the inbred Deli dura population, whereas the others were for outcrossed populations, and show more evidence of additive genetic variance (narrow sense heritability). Apart from this, no very clear pattern can be seen, but it is worth noting that bunch index does not generally have a lower heritability than other characters, in contrast to our results.

Selection and plant density. At a density of 56 palms/ha there is no overlap between the crowns of adjacent palms, and interpalm competition for light is probably negligible. From Table 3 it will be seen that, during the second and third years of production, the yield per palm at 148/ha is only 11% below that obtained in the absence of competition. At 186/ha, yield per palm is reduced by 28%. The amount of interpalm competition in years 4–8 is greater, because of the increase in leaf area index. Thus study of yields in years 4–8 allows us to assess the performance at high density of palms selected under a low level of competition in years 2–3.

The results in Table 4 provide the first clear evidence that selection of palms with high bunch index might produce material capable of yielding well at higher than normal densities. Selection for high bunch index is more effective than selection for high yield or high net assimilation rate. The differences are small, and we have not attempted to assess their statistical significance, but it may be noted that the palms selected for high early yield had above average vegetative dry matter requirements and annual height increments, and considerably above average leaf areas. In other words, they were highly competitive palms, and would probably not yield so well in a more uniform population of equally vigorous palms. Palms selected for high NAR were also well above average height. In contrast, the palms selected for high bunch index were average in vegetative vigour. Thus in a more uniform population, the advantage of high bunch index palms would probably be greater.

In work with cereals it has similarly been shown that, for widely spaced plants, harvest index is a better predictor of crop grain yield in a normal crop than is yield of the spaced plants (SYME, 1972; FISCHER & KERTESZ, 1976; DONALD & HAMBLIN, 1976).

Selection for high leaf area ratio, or a high leaf area per unit vegetative dry matter, appears useful theoretically (CORLEY, 1976), and LAR generally has a high heritability, but in experiment 2 selection for leaf area ratio was not effective in giving palms tolerant of high density planting. TAN (1978) suggested selecting palms with short fronds, arguing that the planting density for such palms could be increased without increasing interpalm competition. Rachis length (RL) has a high heritability, but selection for short rachises appeared ineffective (Table 4). Selection for various combinations of characteristics, such as above average LAR with high bunch index, or below average VDM with high bunch index, was also tested. The only combinations which were effective were those which included high bunch index, but none gave higher yields than selection for bunch index, and the results are not presented here.

The figures in Table 4 are for yield of fruit, but it is the yield of oil which is important economically. Oil content of fruit bunches was determined in experiment 2, but sampling intensity was too low to give reliable estimates for individual palms. More extensive data was available from experiment 1, where the overall mean oil/bunch ratio was 25.3 percent. Palms selected for high yield of bunches had a lower mean oil/bunch of 23.5 percent. Palms selected for high bunch index averaged 24.7 percent oil/bunch, only slightly below the population mean. Thus, in terms of oil yield the advantage of palms selected for bunch index over those selected for fruit yield might be greater than indicated in Table 4.

The heritability of bunch index appears variable, and may be lower than that for some other characters, so selection might best be based on progeny means, rather than individual palm values. It is worth noting, though, that even where selection of ortets for vegetative propagation is based on highly heritable characters, it will still be necessary to field test the clones produced, before using them in large scale plantings. Reliable estimates of bunch index should be obtainable from such clone trials, and could be used to identify those clones best suited to high density planting, without planting every clone in a density experiment. Preliminary estimates from data of CORLEY et al. (1981) show that variation in bunch index between palms within a clone is less (CV = 5.8%) than within seedling progenies (CV = 7.8, 9.2 and 19.4% for three progenies).

In experiment 2, there was a strong tendency for those palms with the highest bunch indices in the first two years also to have the highest indices later under more severe interpalm competition. Thus where selection for bunch index is intended, it might appear that the low density planting advocated by CORLEY (1976) may have little advantage. With wheat, NASS (1980) showed that selection for harvest index at a high population density was more effective in increasing yields than selection at a low density. Nonetheless, from the results of HIRSCH (1980) quoted above, it seems likely that, in a population of variable vigour, variation in the level of interplant competition would occur at high densities which would tend to bias results. If so, the best estimates of potential bunch index would be obtained from low density plantings, or by restricting attention to the early years in higher density plantings. The latter approach has the disadvantage that data from short periods of recording give lower repeatabilities (Table 2), so until further information becomes available, the former is to be preferred.

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