

SELECTION OF OIL PALM MALE PARENTS FOR OPTIMAL PLANTING DENSITY ESTIMATED FROM MATURE CROWN SURFACE

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ABSTRACT

Our study on selecting pisifera male parents aims at determining yield per palm as well as the optimal planting density of the tenera offspring. The data pattern came from *dura* x *pisifera* testcrosses, planted at 135 and 160 palms ha⁻¹ in North Sumatra, Indonesia, from which the breeding values of 15 *pisifera* parents of Ghana origin are estimated. Optimal palm densities were assessed from the leaf surface at mature canopy, obtained from the product of number of green leaves with the (asymptotic) maximum leaf area (0.95 L-max), inferred from a logistic growth curve fitted through leaf area values versus palm age. The time to reach the optimum values ranged between 5.5 to 7.9 years after planting. Amount of light under the palms, measured by the vigor of *Mucuna* cover crop, scored 50 and 67 months after planting (cc-score), considerably varied among *pisifera*. The clear negative correlation between yield and cc-score reveals that male parents selected for yield during the early years of production may generate tenera offspring palms that are highly light-competitive later on. To circumvent this drawback, this study suggests to select *pisifera* parents for yield per hectare at optimal palm density instead of yield per palm.

Keywords: *pisifera* selection, optimal planting density, leaf area index for maximum bunch yield.

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INTRODUCTION

Selection of oil palm parents should take into account not only the yield per palm but also the expected optimum planting density, *i.e.* the density giving the highest cumulative yield per hectare, as argued by Hardon *et al.* (1972); Breure and Corley (1983).

Furthermore, the Nigerian Institute for Oil Palm Research (NIFOR) records quoted by Sparnaaij (1969) indicate that progenies differing in vegetative vigor may have unequal optimal planting densities. Support came from Sly and Chapas (1963), who reported that (individual) progenies are only able to

achieve highest yield per hectare at specific planting densities. Statistically significant differences in optimal density between clones were reported by Corley and Donough (1992), which provides further evidence that progenies need specific palm densities to express the full yield potential. It is therefore timely to obtain the actual optimal planting density of *dura* x *pisifera* (*tenera*) offspring descending from individual parent palms.

Suggestions have been made to take growth parameters into account in the selection of parent palms, in addition to yield per palm (Hardon *et al.*, 1972). Including growth parameters became feasible when Hardon *et al.* (1969) and Corley *et al.* (1971) had evolved non-destructive measurements for estimating leaf area and dry matter production of oil palm. It was suggested that particularly leaf area is an important parameter for estimating potential yield per hectare.

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Breure and Corley (1983) confirmed that young palms selected for high yield per palm tend to have a considerably higher leaf area than the remaining ones. In other words, they are highly competitive palms and would probably not yield well in a more uniform population of equally vigorous palms. They concluded that, instead, selection for high bunch index, *i.e.* the proportion of total dry matter used for bunch production, is more effective. These young palms yielded well at a later phase when inter-palm competition for light has increased, in contrast to palms exclusively selected for high yield.

Smith *et al.* (1996) found that in the early years of production optimal density was mainly related to rachis length: palms with short rachises compete less than those with longer rachises. Later on, when leaves were overlapping, the optimum was more related to leaf area.

Breure (2010) showed that optimal density could be determined at an early stage. Therefore, the leaf area at maximum crown size (L-max) was applied, which was estimated from a logistic growth curve fitted to annual leaf area values up to only eight years after planting. Multiplying L-max by the number of fronds gives the total leaf area per palm, which together with the optimal leaf area index (LAI), *i.e.* total leaf surface per hectare for maximum yield per hectare, was used to estimate the optimal palm density at mature crown surface.

In the present study, mature leaf surface per palm was estimated from the product of 0.95 L-max, instead of the asymptotic value, and the actual number of green fronds at a mature canopy, as reported by Gerritsma and Soebagyo (1999). To estimate the time to reach the optimum planting

density, we also calculated the time after planting to reach 0.95 L-max ($t_{0.95}$).

Increasing LAI by closer planting of the palms enhances light interception by the foliage. Initially, the increment of intercepted light by the leaf surface proportionally benefits the amount of gross carbon dioxide (CO₂) assimilation, and hence, the rate of conversion of absorbed solar radiation to carbohydrates (CH₂O). Individual leaves are, however, light-saturated already at about 30% of full sunlight (Gerritsma, 1988), so the main part of light absorbed beyond this level is wasted. At a certain level of LAI, therefore, diminished light use efficiency due to poor light distribution over the various layers of the canopy (as a result of closer spacing) restricts a further increase in carbohydrates for total dry matter (TDM) production. Since vegetative dry matter (VDM) production still continues to increase linearly at that stage, a further increment of LAI reduces bunch dry matter (BDM) production. This intrinsic relationship of TDM, VDM and BDM with LAI is depicted in *Figure 1*, which is based on results of a palm density experiment with AVROS material in Papua New Guinea (PNG), as reported by Breure (1988). *Figure 1* shows the curve of CH₂O incorporated in TDM production and the linear curve of those incorporated in VDM, plotted against LAI. The distance between both regression lines, which is the amount of carbohydrates (CH₂O) available for BDM, shows its largest size at LAI of 4.5, to be regarded as the specific LAI for producing optimal yield per hectare. This value is slightly lower than LAI of 5, a value commonly characterised by a closed green canopy (Lövenstein *et al.*, 1995).

It should be clear that optimum LAI mainly depends on the extent of light penetration through

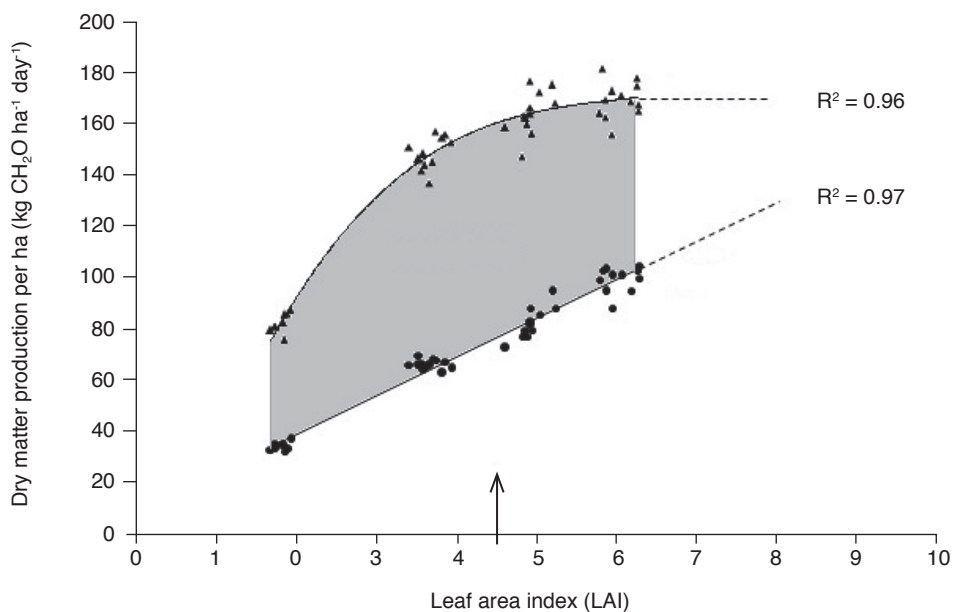


Figure 1. Relation between leaf area index (LAI) and assimilates (kg CH₂O ha⁻¹ day⁻¹) for total dry matter (TDM), vegetative dry matter (VDM) and bunch dry matter (BDM). Points are various sub-plot values for each of the four palm densities (56, 110, 148 and 186 palms ha⁻¹) for the period six to nine years after planting [adopted from Breure (1988)]. Optimum yield per hectare is indicated by a vertical arrow and occurs at LAI = 4.5.

the canopy. Oil palm has a spherical leaf angle arrangement, being a random arrangement of the leaf angles, in which lower leaf layers substantially contribute to overall crop assimilation, as a result of a favourable light distribution. So, we may assume that possible (minor) differences in canopy structure among the mixture of *dura* × *pisifera* offspring palms derived from individual Ghana *pisifera* as well as between the offspring from pure AVROS and Ghana origins have a negligible effect on the extent of light distribution, and hence, on optimal LAI.

Light under the palms is inferred from the vigor of the *Mucuna* covercrop (referred to as cc-score) before canopy closure. Cover crop forms the lowest layer of the total intercepting green leaf surface, so a high cc-score indicates a low light interception by the oil palm canopy. Since, as shown in *Figure 1*, VDM has priority in the allocation of carbohydrates, the cc-score is expected to have an inverse relationship with yield.

Breure (2010) postulated that, based on mean L-max values of a set of Ghana *pisifera* tested in an experiment in South Sumatra, Indonesia, Ghana planting material can be planted at 160 palms ha⁻¹. The present study validates whether this general recommendation applies for individual Ghana *pisifera*. For comparing optimum planting densities of *pisifera*, we used an optimum LAI for maximum yield per hectare of 4.5, being the equivalent of 45 000 m² leaf surface of the palms per hectare.

The ultimate goal of the present study is to select *pisifera* parents for yield per hectare of the *tenera* offspring, based on the product of (estimated) optimal planting density and yield per palm adjusted to the novel optimal density. Finally, the amount of light under the palms, as indirectly defined by the vigor of the *Mucuna* cover crop before its closure, is used to study the relationship between estimated light absorbed by the oil palm foliage and yield.

MATERIALS AND METHODS

Plant Material

This study focuses on selecting 15 *pisifera* (P codes) of Ghana origin, derived from highly-inbred parental crosses, developed at Kade Oil Palm Research Centre, Ghana, using genetic material introduced from NIFOR. The *pisifera* were part of the male parents of *tenera* progenies, generated by ASD from *dura* × *pisifera* crosses, aimed to estimate the breeding values of the parents. The crossing scheme for generating the progenies was according to an alpha design (Patterson *et al.*, 1978). Each *dura* was pollinated by two *pisifera* palms and each *pisifera* pollinated eight *dura* palms.

The progenies were arranged in 16-palm plots, with two replicates each planted at a density of

135 palms ha⁻¹ and 160 palms ha⁻¹; the latter plots were surrounded by a single guard row. The data pattern for individual *pisifera* was thus based on eight *dura* × *pisifera* crosses with 64 palms per cross, resulting in a total of 512 records. The *dura* × *pisifera* progenies were planted at Kisaran, North Sumatra, in 2010. A vigorous, pure, *Mucuna* legume crop was established under the palms in all plots, as shown in *Figure 2*.

Environmental Conditions

Growing conditions at Kisaran are very favourable for oil palm. Soils are alluvial hydromorphic, largely derived from Toba volcanic ash (Foster, 2011), and uniform. Annual rainfall is about 3500 mm, which is well distributed during the year, and 6 hr bright sunshine per day.

Data Collection

Yield. Fruit bunch yield was recorded for seven years from the start of production in 2012.

Leaf area. The area of the first fully expanded youngest leaf was annually estimated during the first eight years after field planting, following the method as described by Breure (2017). A total of 10 leaves were measured (one extra at the start and one in the middle of the eight-year period). A logistic curve was fitted through leaf area values of offspring from each *pisifera* parent. From this curve, the asymptotically attained maximum leaf area (L-max) and the time to reach 0.95 L-max ($t_{0.95}$) were estimated. The method is described by Breure and Verdooren (1995).

Number of fronds. This was measured at 7.2 years after planting. For determining a final (stable) mature leaf surface at a later date, we used a constant



Figure 2. Vigorous *Mucuna* cover crop one year after planting the oil palm seedlings.

number of 36 fronds per palm, as obtained under estate standards of frond pruning by Gerritsma and Soebagyo (1999).

Canopy light penetration. This was inferred from the vigor of the *Mucuna* cover crop below the canopy at 50 and 67 months after planting (about the time when the canopy had just closed). The global appearance of vigor around individual palms was scored from 3 (vigorous *Mucuna* cover) to 0 (absence of *Mucuna* cover) as depicted in Figures 3 and 4, respectively. Records for individual palms were averaged per plot (referred to as cc-score). Recording was done by several observers, who were carefully calibrated on the index of cc-scoring.



Figure 3. Plot of *Mucuna* cover crop with cc-score 3.



Figure 4. Plot of *Mucuna* cover crop with cc-score 0.

Estimating Optimal Planting Density

The optimal densities (D) of the *tenera* offspring progenies, derived from individual *pisifera*, were estimated for a mature leaf surface from the product of 0.95 L-max and 36 fronds per palm by applying an optimal LAI of 4.5:

$$D = (4.5 \times 10\,000) / [(0.95 \text{ L-max}) \times 36]$$

Yield Per Hectare

The yield per hectare was calculated as the product of the estimated optimal planting density

and the yield per palm. The latter was adjusted, for individual *pisifera*, to the novel optimal planting densities based on the linear interpolation of cumulative yield per palm obtained at the 135 and 160 palms ha⁻¹.

Data Processing

For each of the 15 *pisifera* parents, the General Combining Ability or Breeding Value, *i.e.* the additive genotypic effect of the selection traits, was estimated from mean plot values of the progeny test.

RESULTS

Leaf Area

The asymptotic maximum leaf area (L-max) ranged from 8.41 m² for *pisifera* P6 to 9.46 m² for *pisifera* P30 (Table 1). Optimal densities at mature leaf surface ranged from 139 (P30) to 156 (P6 and P34) palms ha⁻¹.

Table 1 also presents for each *pisifera* the period in years (t_{0.95}) when 0.95 L-max, and hence optimal palm density, is attained. The period varied between 5.5 and 7.9 years after planting (P7 versus P28). There was a non-significant positive relationship (r = 0.35) of L-max with t_{0.95}, indicating that the variation in L-max is only slightly due to the period of area expansion.

Due to a difference in speed of leaf expansion, the mean leaf area between years 2 to 5 did virtually not correspond with L-max (r = 0.18). The poor relationship is illustrated by comparing P7 and P28. Both *pisifera* have nearly the same L-max (9.01 versus 9.17 m²), but differ considerably in mean leaf area for years 2 to 5 (6.20 m² versus 5.09 m²; Table 1). More interesting is that P7 reached 0.95 L-max much earlier than P28 (5.5 versus 7.9 years after planting). Figure 5 depicts the data of leaf area expansion over the years for both *pisifera*.

The mean number of fronds on the palms, observed 7.2 years after planting, ranged between 39 and 41 among *pisifera* (with an average of 40 fronds).

Yield Per Palm and Per Hectare at Optimal Palm Density

Table 2 presents the yield (kg palm⁻¹) for the individual *pisifera*, together with the ranking order. Mean yield per palm density (being 160 and 135 palms ha⁻¹) was 1281 versus 1414 kg palm⁻¹. Assuming a linear decrement of yield per palm as a function of planting density, for each individual *pisifera*, the yield per palm was corrected for the novel (optimal) palm density (*cf.* Table 1) based on an interpolation of yield at the two densities.

TABLE 1. RACHIS LENGTH (cm), MAXIMUM LEAF AREA (L-max), TIME TO REACH 0.95 L-MAX ($t_{0.95}$), MEAN LEAF AREA FOR YEARS TWO TO FIVE AND ESTIMATED OPTIMAL PALM DENSITY (palm ha⁻¹) FOR 15 GHANA *Pisifera*

<i>Pisifera</i> codes	Rachis length (cm)	L-max (m ²)	$t_{0.95}$ (years)	Mean leaf area 2-5 years (m ²)	Optimal density (palms ha ⁻¹)
6	457	8.41	6.5	5.34	156
34	451	8.44	6.8	5.37	156
32	447	8.47	6.6	5.36	155
23	446	8.61	6.6	5.37	153
2	446	8.65	5.8	5.75	152
47	454	8.73	6.4	5.74	151
31	435	8.82	7.7	5.02	149
29	440	8.83	7.5	5.01	149
35	468	8.85	6.7	5.41	149
7	477	9.01	5.5	6.20	146
12	472	9.13	6.8	5.59	144
28	448	9.17	7.9	5.09	143
11	467	9.27	6.3	5.98	142
27	446	9.29	7.5	5.32	142
30	463	9.46	7.5	5.47	139
Mean	454	8.88	6.8	5.47	148
Min	435	8.41	5.5	5.01	139
Max	477	9.46	7.9	6.20	156

adjusted yield per palm and optimal density. As an example, yield per palm for P34 was clearly lower than for P30 (1342 versus 1426 kg palm⁻¹). Applying the optimal density calculation, however, there was only a minor difference between P34 and P30 (204 versus 206 t ha⁻¹).

Based on yield per hectare, P32 is now clearly the best parent instead of P30, which would be conventionally selected for yield per palm (1426 versus 1403 kg palm⁻¹ for P30 and P32, respectively).

Relationship between Yield per Palm with cc-score

As expected, the inverse relationship of yield per palm with cc-score was highly significant ($r = -0.74$; $p = 0.01$). Figure 6 shows, for the combined results of the two densities, the yield for the first seven years of production versus cc-score for each *pisifera*. Note, for example, the data of P30, for which a high yield is combined with a low cc-score and *vice versa* with the data of P29. In other words, the offspring of *pisifera* palm P30 with the highest light interception (as inferred from the cc-score) generates the highest yield. In contrast, the offspring of palm P29 with the lowest light interception produces the lowest yield.

TABLE 2. BREEDING VALUES OF YIELD (kg palm⁻¹), ADJUSTED YIELD FOR THE NOVEL DENSITIES (kg palm⁻¹) AND YIELD AT OPTIMUM PALM DENSITY (t ha⁻¹), TOGETHER WITH THEIR RANKING (R), FOR 15 GHANA *Pisifera* DURING THE FIRST SEVEN YEARS OF PRODUCTION

<i>Pisifera</i> codes	Yield (kg palm ⁻¹)			R	Adjusted yield (kg palm ⁻¹)	Yield (t ha ⁻¹)	R
	160 ha ⁻¹	135 ha ⁻¹	Total*				
32	1 365	1 433	1 403	5	1 378	214	1
2	1 307	1 497	1 411	3	1 367	208	2
11	1 319	1 509	1 416	2	1 456	207	3
30	1 328	1 511	1 426	1	1 481	206	4
12	1 294	1 495	1 403	4	1 421	205	5
34	1 296	1 379	1 342	10	1 310	204	6
7	1 286	1 472	1 376	6	1 390	203	7
6	1 268	1 330	1 303	12	1 277	200	8
28	1 316	1 431	1 369	7	1 392	200	9
31	1 299	1 383	1 342	9	1 336	199	10
47	1 245	1 449	1 343	8	1 320	199	11
35	1 256	1 377	1 321	11	1 311	195	12
23	1 246	1 300	1 274	13	1 261	193	13
29	1 186	1 342	1 256	14	1 254	187	14
27	1 208	1 295	1 253	15	1 272	180	15
Mean	1 281	1 414	1 349	-	1 348	200	-
Min	1 186	1 295	1 253	-	1 254	180	-
Max	1 365	1 511	1 426	-	1 481	214	-

Note: *Breeding values based on all four replicates.

Table 2 also presents the values of the adjusted yield (kg palm⁻¹) and yield per hectare (t ha⁻¹), along with the ranking order.

Evidently, the ranking order of yield per palm for individual *pisifera* considerably deviates from that of yield per hectare, based on the product of

Factors Affecting cc-score

A multiple regression analysis is employed, in which mean rachis length and leaf area for years two to five (corresponding to the canopy size that exerted an effect upon *Mucuna* vigor) are used as

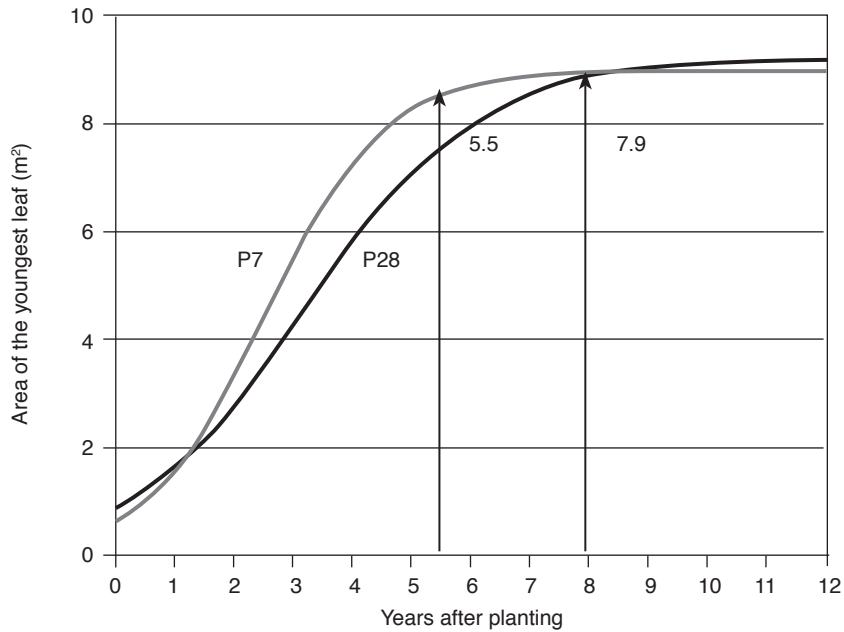


Figure 5. Leaf area versus time (years after planting) for pisifera codes (P) 7 and 28 of Ghana origin. The time to reach 0.95 L-max ($t_{0.95}$) is indicated by a vertical arrow.

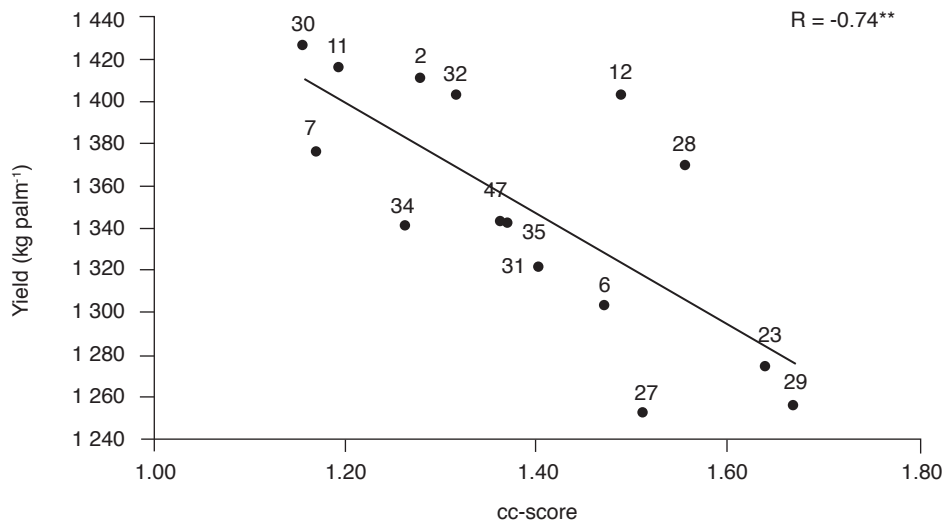


Figure 6. Yield (kg palm^{-1}) during the first seven years of production vs. cc-score for 15 Ghana pisifera.

predictors of cc-score. The result revealed that the cc-score is only significantly affected by leaf area ($r = 0.65$; $P = 0.01$), which acts upon the light penetration through the canopy.

DISCUSSION

Yield Per Hectare

Our investigation proves that it makes sense to focus on the optimal planting densities for *tenera* offspring descending from individual *pisifera*

parents. Accordingly, *pisifera* parents can be selected for potential yield per hectare instead of yield per palm (cf. Table 2). Obtaining the optimal density is also essential for recommending companies that plant the *tenera* offspring descending from individual *pisifera*.

Optimal Density

Our investigation showed that the suggestion of Breure (2010) to plant *tenera* material from Ghana origin at the same density of $160 \text{ palms ha}^{-1}$ appears to be premature. Clearly, optimal densities, as

estimated in the present study, show a variation of 139 to 156 palms ha⁻¹ among the offspring from individual Ghana *pisifera* parents. Such diversity in growth is surprising after four generations of inbreeding. With less inbred *pisifera*, the variation becomes substantially higher, as Breure (unpublished data) found, for example, for *pisifera* of Nigeria origin (124 to 157 palms ha⁻¹). This novel outcome justifies our strategy of selecting individual *pisifera* for optimal planting density. Selected *pisifera* are cloned to ensure sufficient production of pollen.

One may argue that the optimal LAI obtained from the palm density experiment in PNG (cf. Breure, 1988) could be different from the optimum at the Kisaran site. However, environmental conditions at the PNG site, in terms of the proportion overcast and clear sky, the main factor influencing light penetration (Van Kraalingen *et al.*, 1989), are similar to that at Kisaran, being 5.6 hr per day bright sunshine at PNG versus 6 hr at Kisaran.

It is, therefore, reasonable to adopt the optimal LAI value of 4.5 as obtained by Breure (1988) in order to estimate optimal densities of the individual Ghana *pisifera* in the present study. It should be noted that our focus is on differences in estimated optimum density between individual *pisifera* in one origin (Ghana). So even if there might be a slight difference in optimum LAI between the AVROS and Ghana origins, this would not affect the main objective of this study.

The present study still measures leaf area of individual palms for determining LAI at a mature canopy. With the modern technique of using LAI-2000 palm canopy analyser (PCA), a more rapid non-destructive measurements of LAI can be made. However, Awal and Wan Ishak (2008) found that this method grossly overestimates LAI in young palms and underestimates LAI for palms older than six years. The LAI-2000 may thus only be used for comparing LAI values and not for estimating optimum palm density or the time to reach the optimum.

Leaf Area

Previous suggestions of applying early mean leaf area as an additional selection trait appear to be opposed. We obtained only a small relationship ($r = +0.18$) between mean leaf area for the years two to five and L-max, confirming result of Breure (2010) for several *pisifera* origin. A difference in rate of leaf expansion is the main cause, as can be illustrated by a comparison of leaf expansion between P7 and P28. Both attain identical 0.95 L-max values, but the plateau level occurs 2.4 years earlier for P7 than for P28, resulting in a much higher mean leaf area for P7 during years 2 to 5 (6.20 versus 5.09 m² for P28).

Yield Per Palm

Our study confirms a strong negative correlation between mean yield per palm for the first seven years of production and cc-score (cf. Figure 6), which implies that yield is related to the amount of light captured by the oil palm canopy, for which, as mentioned above, variation in leaf area is mainly responsible. At a density of 160 palms ha⁻¹, as Breure suggested in his 2010 report, the most productive *tenera* palms from all Ghana *pisifera* may, therefore, later on exceed the optimum LAI. An LAI value for maximum yield per hectare that is higher than 4.5 (cf. Figure 1) could occur for those *pisifera* parents that combine a high mean leaf area during canopy expansion with a high L-max value, such as, for example P30 and P11 (cf. Table 1). One way out is to select the palms during the period when the leaf surface has stabilised, for example, for the yield from years 6 to 9 of production, as adopted by the CIRAD system of selection (Durand-Gasselin *et al.*, 2002). Besides the considerably delay before parent selection can take place, this method still only compares the individual palm production as that obtained at the density of the experiment. As a consequence, exploration of the potential yield per hectare remains outside scope. To circumvent this shortcoming, we determined planting densities that attain an optimum LAI of 4.5 at mature crown size. In order to correct the yield per palm (by linear interpolation) for the novel optimal planting densities, it is crucial to plant progeny trials at two commercial planting densities, as we did in the present study.

Commercially-used Planting Densities

It should be realised that our estimates of optimal planting densities can only be used as a guide for commercially-used densities, being 128, 135, 143, 151 and 160 palms ha⁻¹. Slightly adjusting the estimated planting density to practical densities would virtually not affect the expected yield per hectare of the *tenera* produced. The reason is that the optimal yield per hectare has a fairly broad plateau across a range of densities (Corley and Tinker, 2016). For various reasons, it makes sense to increase our estimated density. First of all, Breure (1985) found that a higher planting density significantly reduced L-max, which is the key factor for determining optimal density. Second, although leaf area stabilises at a by and large fixed value, optimal density tends to increase again after the area of individual leaves reach the maximum level (Breure, 1988; Palat *et al.*, 2012). Higher palm density would enlarge fruit set, and hence, percentages oil per bunch and kernel per bunch, as observed in various trials (Breure *et al.*, 1990; Donough and Kwan, 1991; Rao *et al.*, 1992; Nazeeb

et al., 2007). The optimum for oil yield is, therefore, higher than that for bunch yield. Note also that higher density planting allows losses of palms in older plantings due to disease, for example, *Ganoderma* (Nazeeb *et al.*, 2007).

A final point in favour of higher density than the levels estimated in this study is that, due to a lower LAI, the optimum density is higher during the period of leaf expansion before mature crown size (0.95 L-max) is reached. Such a situation is particularly relevant for those progenies having a relatively long period to attain 0.95 L-max. Offspring from P28 is an example. The relatively long period of immature canopy ($t_{0.95}$) of P28 would increase the life time optimum more than, for example, offspring from P7 (Figure 5).

On the other hand, caution is required for areas that are prone to surface water run-off. Then a lower adjustment should be applied to ensure adequate ground vegetation in order to prevent substantial losses of top soil and applied fertilisers that are used. The full benefits of ground cover in mature plantings have been described, for example, by Giller and Fairhurst (2003).

The choice of the final density should, however, take into account the environmental conditions at the site. For palms growing in less optimal conditions than at our study, the mature leaf area (L-max) remains lower, resulting in higher optimal densities. Phang *et al.* (1977) showed, for example, that maximum leaf area considerably varies for inland soils in Malaysia, according to type and depth of the soil.

It could be argued that optimal density also depends on frond angle: For a total leaf surface, less light is captured when the frond angle is more erect (erectophyle) than horizontal (planophyle). However, Breure *et al.* (in preparation) found only minor differences between *tenera* offspring from six distinct *pisifera* origins in the degree at which light penetrating through the canopies is intercepted.

Speed of Canopy Expansion

The considerable difference in $t_{0.95}$ and hence, the period for reaching optimal density, is of interest. Breure (1985) compared single palms with slow and rapid crown expansion and found that the latter palms had a substantial higher bunch yield per palm during the first seven years of production. By shortening the time to reach optimal planting density through selection for rapid crown expansion, therefore, the cumulative yield for the entire life span would increase. Early plateau yield also allows quick financial returns and a more efficient use of the milling capacity, which are particularly important for newly established plantations. Moreover, rapid crown expansion reduces the costs for weeding the legume cover crop and makes planting at high

density followed by the need for thinning a less useful option. In that respect, P7 with the shortest period of expansion would be a better parent than those with a slightly higher yield per hectare but higher $t_{0.95}$ values (*cf.* Table 1).

CONCLUSION

Pisifera parents are female-sterile, reason why their selection is based on the performance of their *dura* × *pisifera* (*tenera*) offspring. Yield per palm of *tenera* palms from individual *pisifera* parents show a highly significant inverse relationship with degree of light interception before canopy closure, as inferred from the vigor of the *Mucuna* ground vegetation (cc-score). In other words, relative darkness reigns under very productive palms. Since the cc-score shows a strongly negative correlation with mean leaf area, the conventional selection of individual *pisifera* for high yield per palm may produce *tenera* offspring that in later years exceed the optimal LAI, *i.e.* the total leaf surface per unit ground area for obtaining maximum yield per hectare. Otherwise, *tenera* from a less productive *pisifera* parent may not even reach the optimal LAI.

To circumvent this drawback, we estimated the planting densities that give optimal LAI at mature crown size. This optimum was reached at different periods after planting.

The ranking of the yield per hectare (of the offspring) at optimal density considerably deviates from that of the yield per palm, which is conventionally applied for selecting parent palms.

For the selection of *pisifera* parents, we recommend to focus on the yield per hectare of the *tenera* offspring and to shorten the period of attaining the optimal planting density by selection for rapid crown expansion.

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