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Planting Density—Early Effects on Growth Pattern of Hevea Brasiliensis

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198-346 t/h.

Stands of 80–140 trees per acre planted in equilateral triangular patterns as established buddings of clone PB 5/51 grew in four discernible phases prior to tapping. Phase one lasted two years during which tree growth was not affected by planting density. Phase two lasted between six months and one year, when inter-tree competition was slight but more rapid closure of the canopy in the higher densities shaded and depressed the leguminous ground covers earlier. The covers competed least with trees planted at high density and, as a result, tree growth was best in high density plots. Phase three was a transition during which growth rate remained unaffected by density. In the final phase, competition related to ground cover vigour was completely masked by increasing inter-tree competition—the lower the density, the better the trees grew. Finally canopy was more squat with lower density, and such planting gave better bark thickness and higher yield per tree per tapping. Density, however, had no practical significance regarding initial tappability and yields per acre were similar at all densities.

Whenever labour costs on estates are high and the price of rubber is low, yield per tapper is of increasing economic importance compared to yield per acre. Under such circumstances, *Hevea* is more profitable if planted at moderately low densities, as has been indicated by various density trials in the past (SCHMOLE, 1940; WESTGARTH AND BUTTERY, 1965; L'INSTITUT DES RECHERCHES SUR LE CAOUTCHOUC AU CAMBODGE, 1959 to 1964). Recent considerations on the economics of tapping (WATSON, 1965; RUBBER RESEARCH INSTITUTE OF MALAYA, 1967a; BARLOW AND LIM, 1967) have also supported this conclusion.

In general, density trials have indicated that, as the number of trees per acre increases, the following results are seen:

(a) girth increment rate falls off;
(b) percentage of untappable trees increases;
(c) bark renewal rate during tapping is poorer;
(d) yield per acre rises;
(e) yield per tree falls and, accordingly, so does yield per tapper; and
(f) acreage tapped per tapper falls.

To complicate this situation, there is also the possibility, at least on the heavier Malayan inland soils, that the growth and yield responses to nitrogen fertilisation of tapped trees may become greater as the stand per acre is reduced (MAINSTONE, 1963). Thus, within a range of densities acceptable to estates, there may be an important economic inter-relationship between density and fertiliser policy after the commencement of tapping. The experiment discussed here was designed to investigate this relationship. This paper reviews the effect of density prior to tapping upon the growth of trees.

EXPERIMENTAL

Four densities – 80, 100, 120 and 140 trees per acre – are compared in the trial, a minimum of four levels being statistically essential to establish the true form of any response curve. Various considerations influenced the range of stands per acre (s.p.a.) chosen. The highest density was selected because the findings of a pre-war Malayan trial indicated that on estates a stand of 120 per acre is desirable by the tenth year after planting (RUBBER RESEARCH INSTITUTE OF MALAYA 1956). Further, at the time of

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planning the present experiment, cumulative yields from the quoted Malayan trial (see also BUTTERY AND WESTGARTH, 1965) indicated that optimum profitability should result eventually from stands within the range 110–140 trees per acre. These indications did not allow for the possible, and increasingly superior, yield responses gained from fertilisation at still lower densities (MAINSTONE, 1963). Accordingly, eighty was the lowest s.p.a. included in the trial discussed here.

Next, it was necessary to decide upon the planting distances. From work in Sumatra (VAN SCHOONEVELDT, 1951), it was concluded that the effect on girth of the distance apart of the trees in the rows was of great importance, whereas the distance between rows became insignificant once it exceeded 30 feet. A complementary conclusion can be drawn from a Malayan hedge planting experiment (RUBBER RESEARCH INSTITUTE OF MALAYA, 1961). Considering only the hedge plantings with 2¼–6 feet between trees in rows and 50–80 feet width of the avenues, the following correlations are obtained.

Girth and planting distance between trees in rows;

$r = +0.8985$ (significant at 0.1 % level)

Girth and original planting density;

$r = -0.0980$ (not significant).

Thus, in relation to girth, the value of reduced planting density will probably be greatest if the minimum distance between trees at a given density is the maximum possible. Therefore, the trees were planted in the trial according to equilateral planting systems. This method allows a maximum period of free growth and should lead to a minimum of distortion of the natural shape of the crown. The extra time required for tapping operations in such a planting as opposed to a rectangular one of similar density is probably not important, as may be inferred from BARLOW *et al.* (1966).

The ideal requirements in studies involving density were thus met, as far as it was practical. The desirability of starting with uniformly developed and vigorous planting material was achieved by using the Dunlop polythene bag technique of planting out established buddings with root systems and scions untrimmed (MAINSTONE, 1962). To reduce root disease incidence (and thus to prevent yield losses), a complete mechanical clearing was made prior to planting (NEWSAM, 1963 and 1967) and leguminous ground covers were planted—such a cover policy would also have been beneficial to tree growth (WATSON, 1960; MAINSTONE, 1960). Also for uniformity a wind resistant clone is desirable and so PB 5/51 was chosen (PAARDEKOOPER, 1965). A potential high-yielder, this clone has one disadvantage for density work; its crown has a conical fir-like shape, so that it possibly responds more favourably to low density planting than the majority of clones now recommended for planting in Malaya (RUBBER RESEARCH INSTITUTE OF MALAYA, 1967b).

Throughout immaturity, there were repeated checks by foliar analysis to ensure that the nutritional status of the trees in relation to current knowledge was satisfactory. Modification of scheduled fertiliser applications was sometimes necessary—fertilisers were applied at similar rates per tree, but quantities per acre were evened up by broadcasting the necessary extra quantities to ground covers in plots with stands of 80, 100 and 120 trees per acre.

A wide range of measurements has been recorded and these are summarised and reviewed here. Measurements have been restricted to sampling-cores of plots. Details of sampling-core sizes according to s.p.a. are included in *Table 1* which also provides other information on experimental design and history.

RESULTS

Regularity of Establishment and Development of Trees

Previous work on density trials was influenced by unevenness of establishment of stands and ultimately by the marked suppression of growth of the weaker trees in plots with the highest densities. The influence of the former has not been important in the current trial, while the latter is unlikely to develop to an appreciable extent.

Uniformity, initially obtained by the nature and selection of the planting material used, was

TABLE 1. EXPERIMENTAL DETAILS

Site — Bahau district of Negri Sembilan, West Malaysia.
Soil type — A good Munchong/Serdang/Gajah Mati complex (Leamy and Panton, Malaya 1966).
Lay-out — Four replications each containing four blocks with each block divided into four square one-acre plots to which the various densities of planting were allocated at random.
Acreage — 64

Treatments and numbers of trees in sampling cores

Stand per acre	Planting distance in feet—side of equilateral triangles	Number of trees in plot sampling cores
140	18.97	39
120	20.44	39
100	22.42	42
80	25.08	33

Date of planting rubber as second storey established buddings in polythene bags
Replication I — 16–19 October 1962
,, II — 12–15 October 1962
,, III — 20–23 November 1962
,, IV — 24–27 November 1962

Cover planting — Seed of *Pueraria phaseoloides*, *Centrosema pubescens*, *Phaseolus calcaratus* and *Calopogonium mucunoides* was drilled in August and September 1962 and establishment was excellent except in the poorer soil areas of Replication IV.

maintained throughout by the cultural techniques employed. Some 84% of trees were branching at twelve months* and s.p.a. had no influence. The mean coefficient of variation for girth at thirty months was 11.3% and it fell to 7.6% prior to tapping. Uniformity was not influenced by planting density.

The absence of a large proportion of runts in high s.p.a. plots (*i.e.* 140 trees per acre) was in agreement with work in Sumatra (SCHMOLE, 1940; WYCHERLEY, 1967a), where it was found that with stands in the range of 80–160 trees per acre, the percentages of untappable trees were similar at any given time. However, with densities in the range 250–444 trees per acre, the percentages of runts increased steeply.

Loss of trees (1.42%) arose mainly at about four years after planting due to the continued effects of localised but severe infection of crowns by *Corticium salmonicolor* and associated wind damage. One small group of trees, located in the perimeter rows of two adjacent plots, was affected by lightning. Only one tree was confirmed as lost due to *Fomes lignosus*.

Measurements for Assessing Pattern of Tree Growth

Attainment of the required girth is a criterion for commencing tapping of *Hevea* rubber. Trunk growth depends largely upon the quality, quantity and efficiency of foliage. Quality was controlled nutritionally at close to the optimum. Quantity of leaf was not estimated prior to tapping. During growth to tappable size, tree efficiency varies according to water availability and leaf efficiency, the former being influenced by bulk of ground covers and the latter by crown shape which affects access of leaves to light. Development of crown shape was studied in three ways: firstly, the rate of horizontal branch spread from tree bases was recorded; secondly, the pattern of development with time of inter-tree competition was judged by noting the percentages of trees with branch spread to half the planting distance; thirdly, heights of trees were estimated. Initially, a pole was used to measure the height. At twenty-four months and subsequently a Haga altimeter was employed. Three sightings at horizontal intervals of about 120° were made per tree. It was not possible to sight satisfactorily the tops of trees on one occasion only. From the height measurements another assessment of inter-tree competition became possible. Differential competition may be assumed when trees in the higher densities commence to grow most rapidly in height while suffering depression of trunk growth rate and rate of branch spread.

Trunk growth and estimated shoot development. The only measurements recorded were those of girth, made at half-yearly intervals.

* All ages refer to months after planting in field.

On these data three aspects of trunk and shoot development are considered:

Girth increments. In the past, girth increments have been used as standards for comparison of growth rates of trees receiving different treatments. This practice can only be considered acceptable if mean girths according to treatments are fairly similar at the commencement of increment periods. This has been the case by and large for the data reviewed here.

Relative growth rate calculated from cross-sectional area of trunk (RGR – CSA). Use of RGR is more valid than that of girth increments since it gives a measurement of growth rate independent of initial girth. RGR – CSA is a precise measurement and, as such, a direct assessment of trunk growth.

Relative growth rate from estimated shoot dry weight (RGR – SDW). This is an indirect measure of growth rate and involves the estimation of shoot dry weight from girth (SHORROCKS *et al*, 1965). Estimates, at least immediately prior to the commencement of tapping, are open to criticism since, at this time, crown shape is influenced by s.p.a. If two trees of identical girth are taken, it is not certain that they will have the same shoot dry weight if the crown of one tree is tall and narrow while that of the other is low and broad.

In the experiment, mean girths at twelve and twenty-four months did not vary significantly according to s.p.a. levels. They were respectively 11.7 and 23.6 cm when measured at 10.2 cm (4 inches) from the ground. Actual girth increments were virtually the same within the same stand during this period, hence any attempt to study RGR was considered unnecessary.

Table 2 outlines data on subsequent girth

TABLE 2. MEAN EXPERIMENTAL GIRTHS (CM) AT 152.4 CM (60 INCHES) AT HALF-YEARLY INTERVALS AND ACCORDING TO DENSITY OF PLANTING ASSOCIATED GIRTH INCREMENTS AND RELATIVE GROWTH RATES (RGR) FOR INCREASE IN THE CROSS-SECTION AREA (CSA)* OF THE TRUNK AND INCREASE IN ESTIMATED SHOOT DRY WEIGHT†

Period after field planting (months)	Mean girth		Aspect	Treatments						
				S.P.A.				S.E.	Significance	
	c‡	f**		140	120	100	80		P	P_L
24 – 30	18.8	23.2	Girth increment	4.52	4.53	4.36	4.26	0.07	< 0.05	< 0.01
			RGR — CSA trunk	0.443	0.435	0.424	0.407	0.007	< 0.05	< 0.01
			RGR — shoot dry weight	0.268	0.263	0.257	0.239	0.006	< 0.01	< 0.001
30 – 36	23.2	29.8	Girth increment	6.83	6.79	6.58	6.59	0.07	< 0.05	< 0.01
			RGR — CSA trunk	0.513	0.511	0.490	0.501	0.010	N.S.	N.S.
			RGR — shoot dry weight	0.310	0.314	0.296	0.303	0.009	N.S.	N.S.
36 – 42	29.8	36.4	Girth increment	6.60	6.58	6.67	6.64	0.07	N.S.	N.S.
			RGR — CSA trunk	0.396	0.396	0.422	0.376	0.015	N.S.	N.S.
			RGR — shoot dry weight	0.240	0.240	0.254	0.228	0.009	N.S.	N.S.
42 – 48	36.4	43.2	Girth increment	6.28	6.64	6.78	7.03	0.06	< 0.001	< 0.001
			RGR — CSA trunk	0.317	0.333	0.345	0.377	0.013	0.05	0.001
			RGR — shoot dry weight	0.186	0.210	0.208	0.228	0.008	< 0.01	< 0.001
48 – 54	43.2	47.7	Girth increment	4.04	4.31	4.81	4.89	0.01	< 0.001	< 0.001
			RGR — CSA trunk	0.181	0.191	0.206	0.212	0.004	0.001	< 0.001
			RGR — shoot dry weight	0.109	0.114	0.128	0.128	0.004	< 0.001	< 0.001

*Relative growth rate for the cross-section area of the trunk is based upon $L_n\ CSA_f - L_n\ CSA_c$.

†Relative growth rate for the shoot weight is based upon $L_n\ W_f - L_n\ W_c$ where the weight of the shoot is calculated from the regression $W = 0.002604\ G^{2 \cdot 7826}$ where W = estimated dry weight in kg and G = girth in cm at 152.4 cm (SHORROCKS *et al.*, 1965).

‡ Measurement or estimate at the commencement of a period.

** Final measurement or estimate at the end of a period.

measurements according to these three aspects. The changes with time for the slopes of the linear regressions for treatments are similar, irrespective of the manner in which the data are considered. Starting at twenty-four months there is apparently superior growth the higher the s.p.a. for a period of six to twelve months. After this, and until forty-two months, growth rates do not vary according to the s.p.a. level. Thereafter, the expected effects of inter-tree competition result in growth being more rapid, the lower the planting density.

It is important to note in *Table 2* that the mean height of trunks to crown bases did not vary appreciably according to s.p.a.; at forty-two and fifty-five months, the mean heights according to s.p.a. varied from 264–269 cm (104–106 inches) and 267–272 cm (105–107 inches) respectively.

Tree height. Heights of trees were estimated at frequent intervals, and the influence of planting density on the rate of increase in height is well demonstrated in *Table 3*. There is a pattern here with four distinct phases. A direct relationship between density and height increment develops between twenty-four and thirty months and is then lost, only to reappear at thirty-six months.

Crown development. Crown form has been studied in relation to lateral branch spread to half the distance between adjacent points according to s.p.a., the actual extent of branch-spread which, after a period, commences to be associated with the intermingling of branches

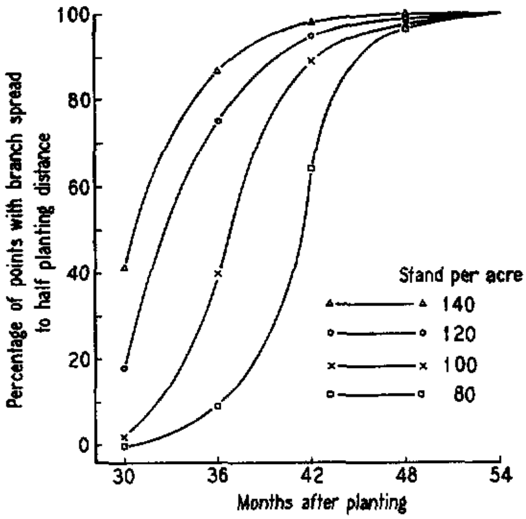
TABLE 3. HEIGHT AND HEIGHT INCREMENTS (FT) OF ALL TREES IN SAMPLING CORES

Age (months)	Mean heights							Mean height increments						
	S.P.A.				S.E.	Significance		S.P.A.				S.E.	Significance	
	140	120	100	80		P	P_L	140	120	100	80		P	P_L
3	3.7	3.7	3.7	3.7	0.1	N.S.	N.S.							
								8.7	8.7	8.9	8.8	0.2	N.S.	N.S.
12	12.4	12.3	12.6	12.6	0.2	N.S.	N.S.							
								7.8	7.8	7.6	7.7	0.2	N.S.	N.S.
24	20.3	20.1	20.2	20.3	0.2	N.S.	N.S.							
								4.6	4.6	4.1	3.9	0.2	<0.05	<0.01
30	24.9	24.7	24.3	24.3	0.2	<0.20	<0.05							
								4.0	3.7	4.0	3.6	0.2	N.S.	N.S.
36	28.8	28.5	28.2	27.9	0.2	<0.05	<0.05							
								9.8	9.2	9.1	8.1	0.2	<0.05	<0.01
48	38.7	37.7	37.3	36.8	0.3	<0.01	<0.001							
								7.6	7.0	5.6	4.5	0.4	=<0.001	<0.001
54	46.3	44.7	42.9	41.3	0.4	<.001	<.0001							

of adjacent trees and an assessment of general crown form based upon the relationship of crown height to the extent of branch-spread.

Figure 1 covers the first aspect and emphasises, especially at thirty months, the very natural and large influence of s.p.a. upon the time when branches of adjacent trees meet. The pattern of the extent of lateral branch spread is given in *Table 4*. Differences in actual mean spread according to s.p.a. differ very significantly from forty-two months as a result of differential rates of growth from thirty-six months onwards.

By deducting the height of branching of trees from the tree height, crown height has been obtained and this, in association with branch-spread data, has allowed presentation of *Figure 2*. Here is demonstrated the effect of s.p.a. upon the development of crown shape. Already at thirty months the influence of increasing density is resulting in narrower and taller conical-shaped crowns. With time, this influence becomes even more strongly emphasised.



Significance:

	30	36	42	48	54
P value	<0·001	<0·001	<0·001	P_L 0·05	NS
S.E. ±	0·28	2·76	2·18	0·30	0·00

Figure 1. Canopy closure

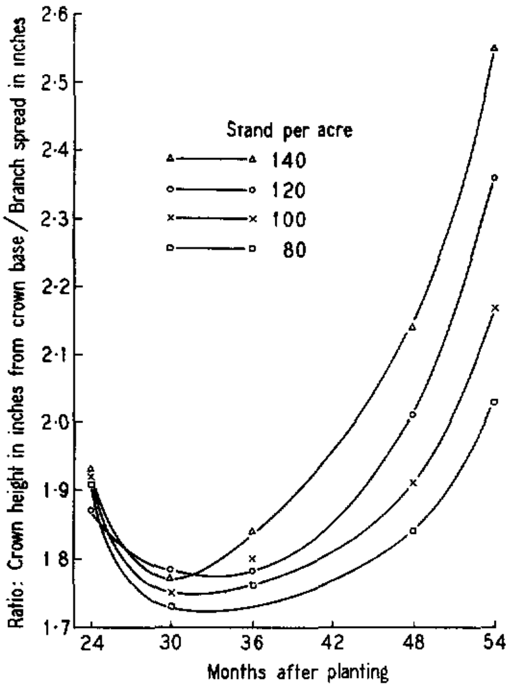
Influence of Ground Covers upon Tree Growth

Between twenty-four and thirty months, growth of tree was more vigorous the higher the s.p.a. This was the case for both trunk development and growth in height. Further, by thirty months, branch-spread was greater the higher the density of planting. It seemed logical, therefore, to conclude that some factor, certainly not inter-tree competition, was allowing trees planted at the highest density to have an overall better growth. Clean weeding around the bases of

TABLE 4. HORIZONTAL BRANCH-SPREAD AND INCREMENTS IN SPREAD (IN.) OF ALL TREES IN SAMPLING CORES

Age (months)	Mean horizontal branch spread							Mean increment in branch-spread						
	S.P.A.				S.E.	Significance		S.P.A.				S.E.	Significance	
	140	120	100	80		P	P_L	140	120	100	80		P	P_L
24	72	73	71	72	1.0	N.S.	N.S.	36.9	34.8	34.9	35.1	0.6	0.05	N.S.
30	109	108	106	108	1.0	N.S.	< 0.05	22.2	25.0	23.4	22.2	0.7	0.05*	N.S.
36	131	133	129	130	1.1	N.S.	N.S.							
42	149	152	152	155	1.1	< 0.01	< 0.001	17.2	19.1	22.7	24.8	0.9	< 0.001	< 0.001
48	*168*	*173*	*179*	*182*	*0.9*	*< 0.001*	*< 0.001*	19.6	20.8	26.6	27.9	1.1	< 0.001	< 0.001
54	177	183	188	193	1.0	< 0.001	< 0.001	8.0	9.6	9.4	10.3	0.7	< 0.20	< 0.05

*P curvation = P_Q = 0.01



	24	30	36	42	48	54
Sig. P	NS	<0·20	<0·01	=	<0·001	<0·001
P_L	NS	Ca 0·05	<0·01	=	<0·001	<0·001
S.E. ±	0·03	0·02	0·01	=	0·02	0·02

Figure 2. Crown form

young trees was practised to allow freer growth. This led to the thought that the more rapid closure of canopies in the higher density plots (see *Figure 1*) might have been associated with a more rapid suppression of ground covers. If this was so, then trees at high densities would suffer less competition from ground covers and hence have greater access to water and nutrients. Some extra nutrients would also have been available from the extra litter produced from suppressed covers. Tree growth at high density planting would thus be generally better for any aspect studied. For these reasons, density of ground covers was estimated at thirty months.

To estimate density, cover depth was measured to the nearest 3 inches at fifty points per plot, each point was at the centre of the triangles formed by the planting patterns. This method was considered satisfactory as overall the ground covers were almost pure *Pueraria phaseoloides* mixed with varying quantities of *Centrosema pubescens* and *Phaseolus calcaratus*. Grasses were negligible in quantity and *Mikania cordata* was rigorously excluded by hand weeding. The findings are presented in *Table 5* which also includes analyses of the ratios of girth increments and RGR of trunks to cover depth. The significance of the ratios is much greater than that of each parameter considered individually. The relationship of tree growth to differential cover suppression thus appears to be established.

From thirty months onwards, differential cover suppression has continued though its contribution to tree growth would seem to be more and more offset by inter-tree competition. Even so it was felt worthwhile to study the situation at thirty-six months. At this time transition from an almost pure legume cover was moderately advanced and measurements of depth of covers could have been misleading. A rough visual survey from four points per plot was therefore made to ascertain the general distribution of cover species and the extent to which they covered the soil. One observer undertook the whole survey so as to reduce personal error. Findings summarised in *Table 6* show two facts of importance: first, cover succession patterns were not affected by s.p.a.; second, suppression of ground covers increased steeply with increase in s.p.a. level. This implies that, prior to tapping, cover weeding will be more costly the lower the planting density. Unfortunately no costings were kept in the experiment.

Commercial Aspects of Density at Commencement of Tapping

Seven months before the first plots were tapped, the thickness of virgin bark was measured and found to average 6.43 mm; this was typical for PB 5/51 (PAARDEKOOPER, 1965). For trees planted at the lowest density, thickness was very significantly superior to that of the highest density plantings but the absolute difference was only 0.23 mm.

At fifty-four months, mean girths of trunks were greater the lower the s.p.a. The maximum difference in mean girths was 1.6 cm. These differences affected the percentages of trees

TABLE 5. TRUNK GROWTH ASSESSMENTS FOR THE PERIOD 24–30 MONTHS FROM FIELD PLANTING IN RELATION TO LEGUMINOUS COVER DEPTH AT 30 MONTHS

Aspect	S.P.A.				S.E.	Significance	
	140	120	100	80		P	P_L
Girth increment in cm at 60 inches	4.52	4.53	4.36	4.26	0.07	< 0.05	< 0.01
RGR — CSA trunk	0.433	0.435	0.424	0.407	0.007	< 0.05	< 0.01
Depth of legumes cover (inches)	16.7	18.0	18.3	18.5	0.4	< 0.05	< 0.01
Ratio of girth increment to cover depth	0.27	0.26	0.24	0.23	0.01	< 0.01	< 0.001
Ratio of RGR — CSA trunk to cover depth	0.0273	0.0247	0.0234	0.0221	0.0008	< 0.001	< 0.001

TABLE 6. VISUAL GROUND COVER QUALITY AND QUANTITY SURVEY TAKEN AT 36 MONTHS

S.P.A.	Visual estimates of percentage make up of species in ground cover					Visual estimate of bulk of ground covers (0 = bare ground 5 = maximum cover)
	Legume	*Ottochloa nodosa*	*Paspalum conjugatum*	*Mikania cordata**	Others *Passiflora foetida*	
140	40	23	31	5	1	2.94
120	41	19	33	7	0	3.50
100	41	17	35	6	1	4.12
80	42	18	28	12	0	4.05
S.E.	4	2	3	3	0	0.17
P	N.S.	N.S.	N.S.	N.S.	N.S.	0.001
P_L	N.S.	N.S.	N.S.	0.20	N.S.	< 0.001

*A vigorous policy to eradicate *Mikania cordata* was successfully introduced after the survey was completed.

tappable at fifty-seven months when the first plots were opened for tapping. For a tree to be tappable, it had to achieve a minimum girth of 50.8 cm (20 inches), at 101.6 cm (40 inches) from the ground level. Trees were opened at 152.4 cm (60 inches) from the ground and tapped on a continuous S/2.d/2 system. The number of trees per acre required for the commencement of tapping was arbitrarily chosen.

Initial indications from *Tables 7* and *8* show that yield has not been appreciably affected by s.p.a. This is largely because the percentages of trees tapped and the levels of yield per tapped tree increase as s.p.a. falls. *Table 7* shows that initially these advantages were in part offset by shorter mean periods of tapping in the lower s.p.a. plots.

Light Passing Through Canopy at Sixty-eight Months

After the first general wintering of trees and when new leaf was fully set in all plots, the amount of light passing through the canopies was recorded in foot candles of light falling on a Megatron photo-electric cell at the base of a black cylinder 4 cm in diameter and 16 cm long, held vertically under the canopy. The time of the measurements was very suitable

TABLE 7. STATE OF EXPERIMENTAL PLOTS AT COMMENCEMENT OF TAPPING (AGES RELATE TO MONTHS AFTER FIELD PLANTING OF TREES)

Aspect		S.P.A.				M.S.D. values for significance			Significance	
		140	120	100	80	0.05	0.01	0.001	P_L	P_Q
Bark thickness in mm at 60 inches at 50 months		6.30	6.43	6.46	6.53	0.12	0.16	0.21	<0.001	N.S.
Mean girth in cm at 60 inches at 54 months		46.9	47.7	47.7	48.5	0.8	1.1	1.4	<0.001	N.S.
Requirements of tappable trees for commencement of tapping: Trees per acre*		70	65	60	55					
Percentage of stand		50	54	60	69					
Percentage of trees tappable at 57 months		56	60	63	69	8	10	14	0.001	N.S.
Percentage of plots opened up for tapping at 57 months		87.5	75.0	68.7	62.5	27	–	–	<0.10	N.S.
Data† regarding 6-month period of opening up plots	Mean yield in lb/acre in the 6 months	297	293	264	237	53	71	–	<0.05	N.S.
57 — 62 months	Mean number of months tapping	5.25	5.37	5.12	4.50	0.95	–	–	0.10	N.S.
Data† regarding first 6 months when all plots were in tapping 63 — 68 months	Mean yield in lb/acre in the 6 months	383	366	351	354	34	–	–	<0.10	N.S.

*Standards considered practically acceptable arbitrarily chosen.

†Yields are for No. 1 + No. 2 grades of rubber. They are calculated from one yield recording from trees in sampling cores per month for latex (No. 1) and cuplump (No. 2) relating to the same tapping. Dry rubber in latex is calculated from the weight of latex and its dry rubber content. Weight of dry rubber in cuplump is obtained from weight of fresh cuplump against the estate conversion figure.

TABLE 8. YIELD DATA FOR NO. 1 + NO. 2 GRADES DRY RUBBER RELATING TO THE FIRST SIX MONTHS* WHEN ALL PLOTS WERE IN TAPPING

Month	Mean total yield in oz dry rubber per tree per tapping	Aspect†	S.P.A.				S.E.	P_L
			140	120	100	80		
January	1.03	a	100	99	107	134	0.4	<0.001
		b	18.5	17.6	15.5	15.1	1.0	<0.05
		c	80	86	86	91	1.8	<0.001
February	0.75	a	100	101	116	129	5	<0.001
		b	18.7	14.1	12.9	12.7	1.4	<0.01
		c	80	86	89	91	1.8	<0.001
March	0.35†	a	100	88	89	106	4	N.S.
		b	20.5	20.1	21.0	21.0	2.0	N.S.
		c	85	88	90	93	1.7	<0.01
April	0.45†	a	100	109	126	150	9	<0.001
		b	24.1	20.5	15.6	16.7	1.4	<0.001
		c	85	88	90	93	1.7	<0.01
May	0.90	a	100	111	130	160	8	<0.001
		b	17.8	16.4	15.8	14.9	1.3	<0.20
		c	85	90	91	93	1.5	<0.001
June	0.83	a	100	116	132	167	9	<0.001
		b	21.4	24.3	20.8	18.8	0.8	<0.20
		c	85	90	91	93	1.5	<0.001

*63–68 months (January–June 1968).
†Effect of wintering depressing yield.
a. Relative yields No. 1+No. 2 grades per tapped tree per tapping.
b. Percentage of total crop collected as No. 2 grade.
c. Mean percentages of stands tapped.

as refoliation had not been affected by leaf disease. The summarised findings are presented in *Table 9*. They appear to indicate that whereas the three higher densities of planting have fairly similar quantities of canopy per acre, there is considerable scope for improvement in the lowest density. If full advantage of this scope for improvement can be taken, then the relative vigour of trees planted at the lowest density may well improve considerably over those trees planted at higher densities.

DISCUSSION

The experiment was not planned to produce information on the wide range of yields per acre obtainable from extremes of planting density. It was designed to investigate two aspects in relation to a probably practical range of densities suitable for estates. Firstly, to examine how and why patterns of tree growth vary; this study has been completed for the pre-tapping period. Secondly, the design is such that the economics of exploitation can be evaluated not only for the

TABLE 9. AMOUNT OF LIGHT PASSING THROUGH FULLY SET CANOPY OF TREES AT 68 MONTHS AND FOLLOWING THE FIRST MAJOR WINTERING

S.P.A.	Intensities (ft candles)
140	0.25
120	0.25
100	0.29
80	0.44
S.E.	±.03
P	<0.001
P_L	<0.001
P_Q	<0.05

effect of density, but also for sub-treatment effects including those for differential nitrogen fertilisation.

Because the trunk is the part of the tree which is eventually exploited, its development is very important. There appear to have been four definable phases up to the time when tapping commenced.

Phase I—The initial period during which s.p.a. does not affect growth pattern of trees.

This phase covers the period until some twenty-four months after planting, during which tree establishment and growth are unaffected by the density of planting. Growth of trunks of trees in height and production of branches are also not affected by s.p.a. Furthermore, it seems that neither initial establishment nor later vigour of ground covers is affected by the density of trees during *Phase I*. The absence of measurements to check this point is considered immaterial.

Phase II—The period of differential closure of tree canopies associated with cover suppression which allows all round superior growth of those trees planted at high density.

This phase is of short duration and lasts probably a little more than six months. It is the period during which, at high density, decreased competition from suppressed covers with associated return of nutrients to the soil has a marked effect, while any influence due to inter-tree competition is masked. During this phase, superior trunk growth of trees at high densities is established not only by girth increments but by assessments of Relative Growth Rates (RGR).

The competition from covers in the experiment may well be more important than might be commonly expected on inland soils. Bahau, the location of the experiment, is in the lowest rainfall area of Malaya (WYCHERLEY, 1967b) and the author has frequently observed the depressive effects of water stress on tree growth.

Phase III—The period during which trunk growth rate is apparently unaffected by s.p.a. level.

This phase commences somewhere between thirty and thirty-six months after planting and ends by forty-two months. RGR of trunks are similar, though from thirty to thirty-six months, girth increments are greater with increasing s.p.a. During this phase, the differential effect of s.p.a. on cover vigour continues but its advantage for trees in high s.p.a. plots is offset by the effects of inter-tree competition. Crown form is definitely being altered to be taller and narrower as s.p.a. increases.

Phase IV—The final period before tapping when inter-tree competition predominates.

Trees in low s.p.a. plots grow best. For all aspects of growth during this period, there are reasons for considering that trees planted at the lower densities are developing most satisfactorily. The slower increase in height should have the advantage of decreasing both wind damage susceptibility and the length of unproductive trunk that has to be maintained. The better rate of trunk growth and thicker bark in low density plots are apparently already giving rise to greater yields per tree per tapping.

That the above advantages are not yet fully exploited can be deduced from the light intensity measurements presented in *Table 9*.

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