The Effect of Density of Planting on the Growth, Yield and Economic Exploitation of Hevea brasiliensis Part I. The Effect on Growth and Yield

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A trial of clone AVROS 50 planted at six different densities and observed for twenty-eight years showed that low densities resulted in large trees and high yields per tree, but relatively low yields per acre. The percentage of tappable trees was smaller in the denser plantings, but the number of tappable trees was greater. Root and panel diseases and wind damage were not noticeably affected by planting density. Dry rubber content of latex was slightly depressed, and the average percentage of lump and scrap rubber slightly increased by increased density of planting.

Since the early days of the planting industry there has been much diversity of opinion on the number of trees which should be planted in a given area for maximum profit. Attempts to solve this problem have been made in a number of experiments. Results of the A.V.R.O.S. experiment in Sumatra have been given by DIJKMAN (1951), while some information on the Marchal density trials in Cambodia is given by BOCQUET (1953).

The object of this paper is to examine the results of a long-term experiment at the Rubber Research Institute of Malaya in which clone AVROS 50 was planted at six different densities. The following factors are considered:

1. growth (girth, height and weight)
2. proportion of tappable trees
3. susceptibility to root and panel diseases, and wind damage
4. bark renewal
5. dry rubber content of latex
6. yield per tree and per acre
7. proportion of scrap

EXPERIMENTAL METHOD

The trial compares the following planting densities:

	Planting distances, in feet	*Initial stand per acre*
(a)	30×30	48
(b)	20×20	108
(f)	20 triangular	125
(c)	14×14	222
(d)	12×12	302
(e)	10×10	435

Seedlings were budded in the nursery with clone AVROS 50 in November 1930 and the stumps were planted out at the experimental densities between 1 and 11 November 1930. The experiment occupied a 40-acre field at the R.R.I.M. Experiment Station; the thirty-six plots were arranged in a latin square design so that each planting density was replicated six times.

In 1937, 1938 and 1939 there were applications of approximately 400 lb per acre per

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annum of a standard NPK mixture while in 1947, 1949 and 1951, 560 lb per acre per annum of an NPK mixture was supplied to all plots irrespective of planting density. The trees therefore received varying quantities of fertiliser depending on the planting density.

An important feature of the trial is that no deliberate thinning has taken place apart from the removal of a few diseased trees. Accidental losses, which are discussed later, have been fairly small except for one plot of density (b) which suffered heavy losses as a result of a lightning strike before yield recording started. Data for this plot have been estimated by the 'missing plot' technique as described, for example, by SNEDECOR (1956).

Tapping started in July 1936 when all trees with girths not less than 20 inches (at 40 inches from the union) were tapped on system S/2.d/2.100% at a height of 40 inches. Thereafter, additional trees fulfilling the girth condition were brought into tapping at six-monthly intervals. The panels on these later trees were opened at the tapping heights prevailing on the trees already in tapping. Tapping continued throughout the 1942—1945 period of the Japanese occupation, except for two minor interruptions which occurred for about three months in 1942 and 1943.

The tapping history of the trees was as follows:

Panel	*Date*	*Height of opening*
First	July 1936–Dec. 1940	40 in.
Second	Jan. 1941–Nov. 1945	40 ,,
First	Dec. 1945–June. 1949	40 ,,
Second	July 1949–Jan. 1953	40 ,,
First	Feb. 1953–Dec. 1956	44 ,,
Second	Jan. 1957 until discontinued in Jan. 1959	90 ,,

RESULTS

The Effect of Planting Density on Growth

The relationship between planting density and the annual mean girth is shown in *Figure 1*. The effect of planting density is not very evident until after the fourth year from budding when presumably the crowns are developed and competition is rapidly increasing; from then on growth is obviously retarded in the denser plantings and the differences due to

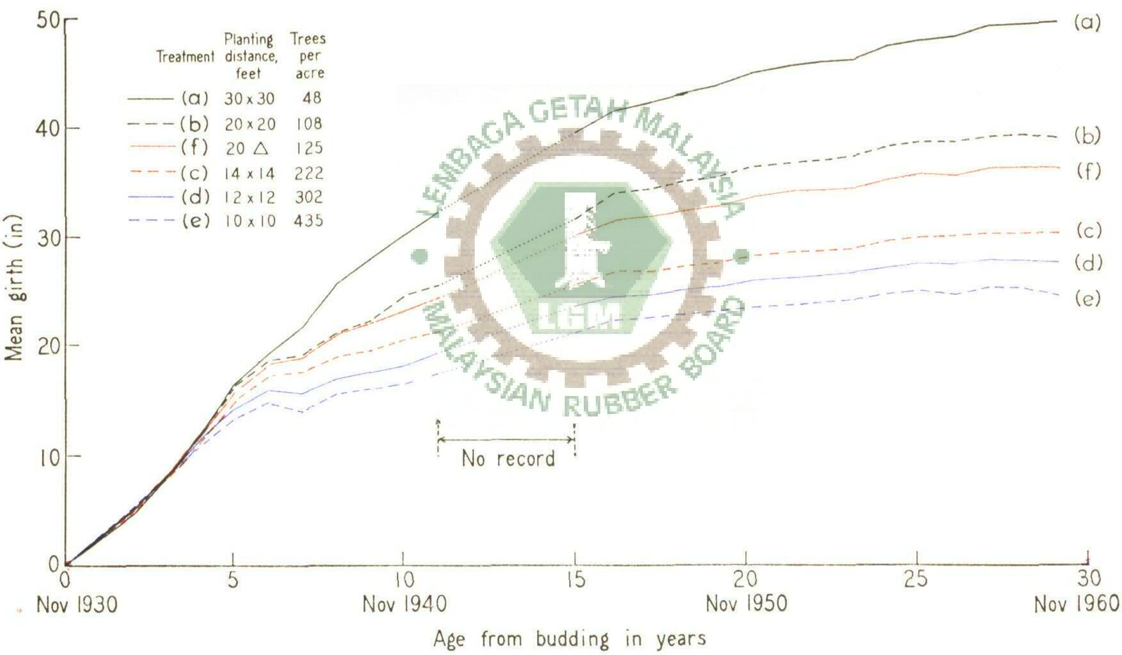

Figure 1. Effect of density of planting on mean girth. (Sixteen years after budding, girth measurements were taken at 40 inches above the union; subsequently they were taken at 50 inches.)

planting density are very evident at the tenth year. In the post-war years the trees planted at a stand of 48 per acre have a mean girth almost double that of trees planted at a stand of 435 per acre. The standard error of the mean girth at a particular density varies from 0.35 to 0.38 in., depending on age, and differences between density means are statistically highly significant.

In 1960, shortly before the area was replanted, measurements of tree height and height to the first branch were made with a Haga altimeter on 10 trees selected at random in each plot.

	(a)	(b)	(f)	(c)	(d)	(e)
Planting density (trees per acre)	48	108	125	222	302	435
Tree height (ft)	88.6	84.6	87.3	83.1	80.4	75.8
Height to lowest branch (ft)	17.8	27.2	29.9	41.1	44.4	46.8

The higher densities produced shorter trees with a much longer expanse of unbranched trunk.

Subsequently five trees of each of the (a), (f) and (e) systems were felled and weighed, giving mean total fresh weights (above ground parts) of 6107 (±311), 2490 (±95) and 1162 (±63) lb respectively. The linear regression of log weight on log girth is highly significant and leads to the relationship: $W=0.439G^{2.428}$, where W is the weight (lb) excluding roots, and G is the girth (in.).

Percentage of Trees in Tapping

Figure 2 illustrates the relationship between planting density and percentage of tappable trees for each year in which records are available. The values used are yearly averages and the ages correspond with the middle of each recording year.

The areas with the lowest density (a), with a stand of 48 trees per acre, have over 90% tappable trees during the ninth year after budding and thereafter this percentage changes relatively little. The highest density (e), with a stand of 435 trees per acre, gives only 60% tappable trees by about the thirteenth year after budding and thereafter the changes in tappable percentage are small. At this high density, in the absence of thinning, over 30% of the trees never reach tappable size.

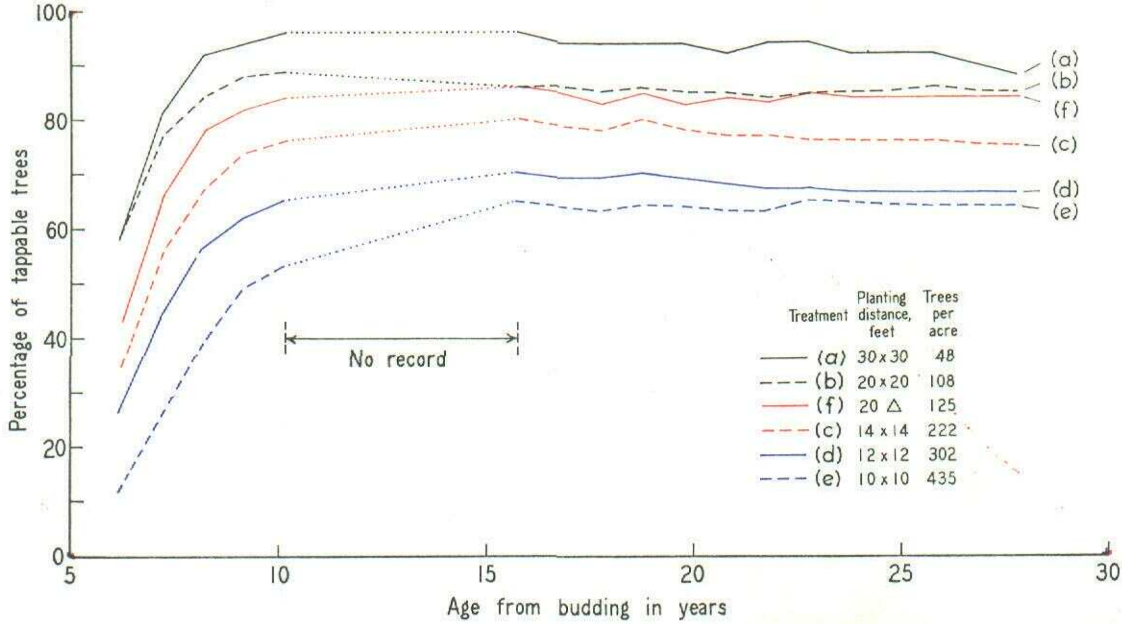

Figure 2. Effect of density of planting on percentage of tappable trees.

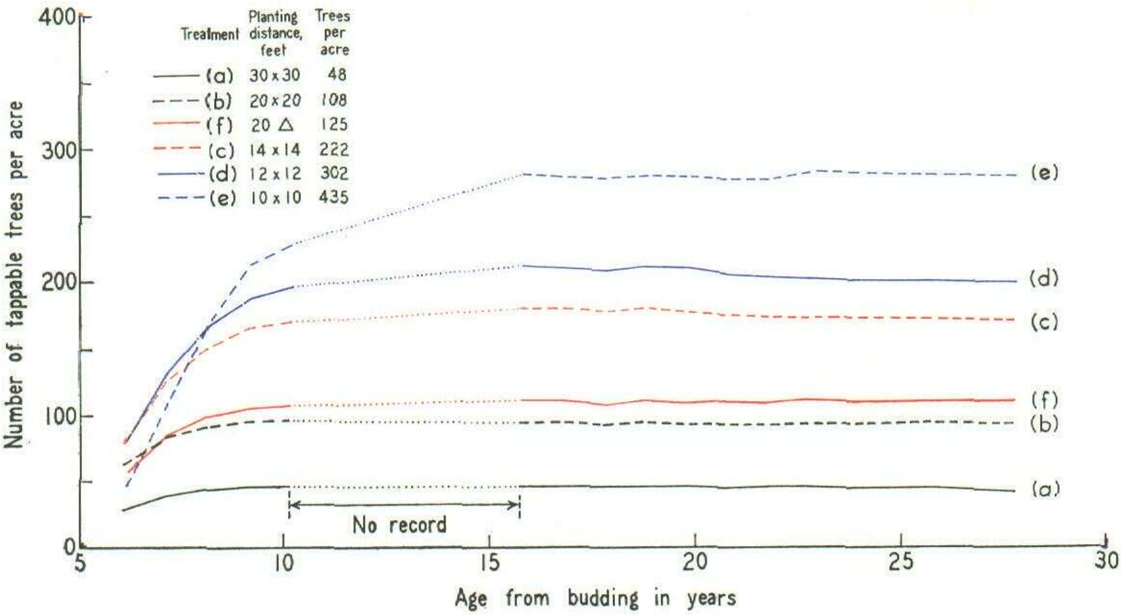

Figure 3. Effect of density of planting on number of tappable trees per acre.

If the numbers of tappable trees per acre (see *Figure 3*) rather than the percentage are compared, it is evident that the denser plantings have the greater number of tappable trees per acre in the ninth year after budding. However, density (d) gave the highest number of tappable trees eight years after budding, while areas planted at density (e) with a stand of 435 trees per acre were notably retarded at this early stage.

A summary of a detailed tree census taken in August 1949, nearly nineteen years after budding, is given in *Table 1.* The effect of planting density on the proportion of tappable trees and the proportion of small trees is very apparent. At a stand of 48 per acre, 93% of the trees are tappable and 1% are too small for tapping. At the other extreme, at a stand of 435 per acre, 64% are tappable and 31% are too small for tapping. Trees in tapping plus small trees account for 90 to 95% of the planting points at each density. The remainder is accounted for by vacancies, planting points omitted because of the position of drains, a few trees suffering from brown bast or root disease, or trees lost through wind damage.

Wind Damage, Brown Bast and Root Disease

Losses due to wind damage have been trivial and there is no evidence to suggest that planting density has influenced the losses with this particular clone (AVROS 50).

The incidence of root disease and brown bast in August 1949 was also generally low. The widest plantings (and largest trees) have the greatest percentage losses from both causes but there is certainly no clear trend which can be associated with planting density.

The percentage of vacancies observed in August 1949 also reveals little influence of planting density although the number of vacancies, twelve per acre, is greatest at the densest planting.

Bark Thickness and Renewal

Bark measurements were first recorded at the end of 1939 about nine years after budding, when the trees had been tapped for about three years on the virgin bark of panel A.

TABLE 1. TREES CENSUS: NUMBER OF TREES IN AUGUST 1949 (AGE 18 YEARS 9 MONTHS) AS PERCENTAGE OF PLANTING POINTS

Planting distance in feet	Trees per acre	Total no. of planting points	Percentage							
			trees in tapping	small trees	vacancies	brown bast	root disease	wind damage	additional vacancies due to drains	total
(a) 30×30	48	168	93.4	0.6	3.0	0.6	2.4	0.0	0.0	100
(b) 20×20	108	385	85.9	4.4	8.8	0.0	0.3	0.3	0.3	100
(f) 20△	125	504	85.6	6.3	6.5	0.0	0.0	0.0	1.6	100
(c) 14×14	222	810	79.6	13.7	4.7	0.0	0.6	0.2	1.2	100
(d) 12×12	302	1188	69.5	24.6	4.0	0.1	0.7	0.2	0.9	100
(e) 10×10	435	1848	64.5	30.7	2.8	0.0	0.1	0.1	1.8	100

TABLE 2. INFLUENCE OF PLANTING DENSITY ON BARK THICKNESS

Planting distance in feet	Trees per acre	9 yrs from budding			17 yrs 2 mths from budding			28 yrs 4 mths from budding				
		virgin bark, mm at 48 in.	1st renewal after 3 yrs		virgin bark, mm at 48 in.	1st renewal after 7 yrs		virgin bark, mm at 90 in.	2nd renewal after 7 yrs		3rd renewal after 5 yrs	
			mm	% v.b.		mm	% v.b.		mm	% v.b.	mm	% v.b.
(a) 30×30	48	9.0	8.1	90	12.4	9.9	80	14.2	8.5	60	7.5	53
(b) 20×20	108	8.0	7.3	91	10.2	8.4	82	11.9	7.2	61	6.4	54
(f) 20△	125	7.8	7.0	90	9.9	8.0	81	11.7	7.2	62	6.4	55
(c) 14×14	222	6.7	6.1	91	8.2	6.6	80	10.5	7.3	70	6.2	59
(d) 12×12	302	6.5	5.7	88	7.9	6.4	81	10.7	7.1	66	6.3	59
(e) 10×10	435	6.1	5.7	93	7.4	5.9	80	10.7	7.2	67	6.3	59

Recordings of virgin and renewed bark were made from 30 trees per plot and average values for each planting density are shown in *Table 2*; further measurements were taken in January 1948 and July 1958 as shown in the Table.

The effect of planting density on virgin bark thickness is clearly apparent in all three recorded years; the larger trees have thicker bark. At nine years after budding the lowest planting density (a) has about 3 mm (or nearly 50%) greater virgin bark thickness than the highest planting density (e); after seventeen years, the difference between (a) and (e) has increased to 5 mm (70%) but after twenty-eight years the difference is only about 30%. How far this change with time is an effect of different heights of measurement (the measurements were at 48 inches after nine and seventeen years and at 90 inches after twenty-eight years) and how far an effect of different observers is difficult to judge. However, it is clear that increased planting density retards the growth of virgin bark proportionally less than it retards girth development, so that the ratio of bark thickness to girth increases with planting density.

Within any one year, renewed bark is thicker at the lower densities of planting. It is unexpected that some measurements of second renewal bark (at twenty-eight years) should exceed those of first renewal bark of the same age (at seventeen years). This is probably an effect of observer differences, and it is preferable in this case to consider the renewed bark as a percentage of virgin bark. It is seen that these percentages are almost the same for each density, within any one year. Measurements of bark of second and third renewal, particularly the latter, may be somewhat misleading, because the renewal is often irregular.

Dry Rubber Content of Latex

Records of dry rubber content are available from 1946 to 1952. The influence of planting density on d.r.c. is not apparent each year, but when the figures are averaged over seven years, a significant negative correlation is established between d.r.c. and stand per acre. This leads to the regression equation:

$$d=46.78-0.002\ n$$

where d is d.r.c. % and n is the number of planted trees per acre. For the range of planting densities considered, this regression corresponds to a reduction of 0.2 d.r.c. units for each increase of 100 trees per acre in the stand.

Yield

Yield recording. Although the trial field has been tapped more or less continuously for about 22 years from July 1936 until January 1959, all yield recording was completely interrupted during the war from July 1941 to December 1945 when the trees were undergoing first-cycle tapping on panel B. In addition, scrap weights are not available for a further two-year period from July 1939 to July 1941. Hence there are yield records of No. 1 RSS sheet for about 18 years, and records of No. 1 RSS sheet including lump and scrap for only 16 years.

Yield recording was carried out on each tapping day between July 1936 and June 1939; latex was converted into sheets and weighed, and lump and scrap were recorded separately by creping and then weighing. From July 1939, however, recording was carried out only twice monthly by latex collection and d.r.c. determination. Annual yields were estimated on the assumption of 160 tappings per year. The yield records were taken only from the inner trees of each plot, and the remaining outer trees, representing about 30 per cent of the total, have been disregarded to avoid bias due to competition with neighbouring plots.

Yield per tree. Annual mean yields per tree of No. 1 RSS sheet are shown in *Figure 4* for the different planting densities. An almost identical pattern was found when total yield per tree, including lump and scrap, was considered, and the comments which follow therefore apply equally well to total yield.

During the first year of tapping, about six years after budding, the differences in the mean yields per tree resulting from the six planting

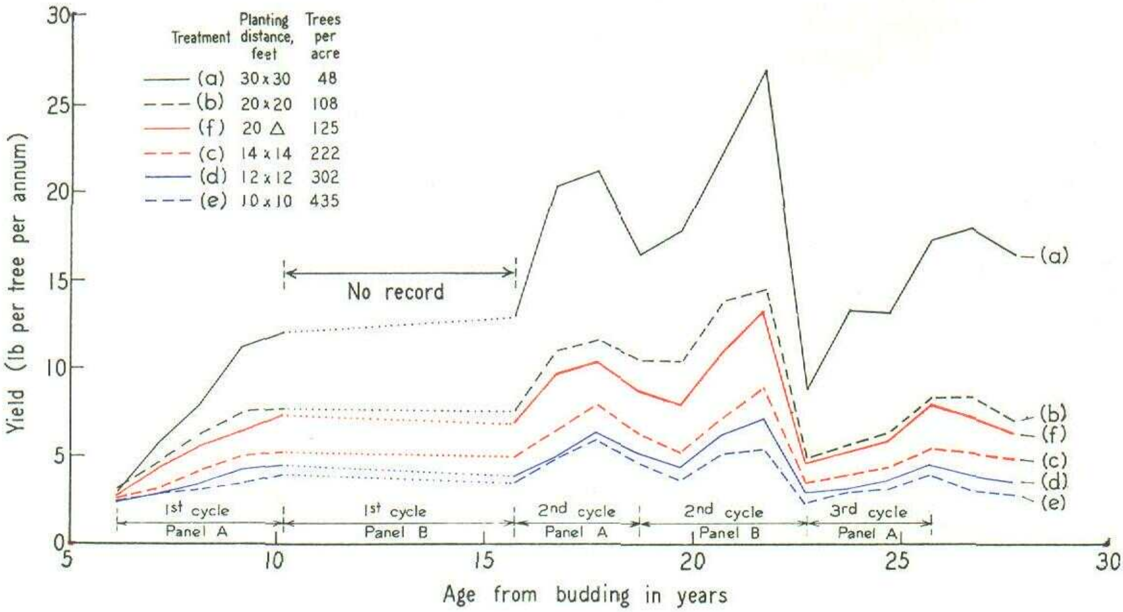

Figure 4. Effect of density of planting on annual yield of No. 1 RSS per tree.

densities are small and not significant. Thereafter, the differences become more pronounced as competition develops in the denser plantings, and a negative correlation is found between yield per tree and stand per acre. At twenty-two years after budding the trees planted at forty-eight per acre have an average yield per tree per annum nearly five times as great as those planted at 435 per acre.

Post-war yields from second-cycle tapping of both panels are generally greater than those obtained from the first cycle on panel A (the first cycle of panel B was largely unrecorded). This increase is true of all the planting densities but is most marked in the lower stands and rises to a maximum at the end of the second cycle of panel B. With all densities the yield falls abruptly on moving into the third cycle of panel A which is second renewal bark, but the relative effects of stand per acre on yield per tree remain much as in the previous cycle. In all years there is a marked positive correlation between the mean yield per tree and the mean girth for the various densities.

Annual yield per acre. The annual variation in mean yield per acre (No. 1 RSS only) is shown in *Figure 5.* The pattern is similar when lump and scrap are included, though this is not illustrated here.

Up to the sixteenth year of tapping (twenty-two years from budding), planting density (a) with a stand of forty-eight trees per acre consistently produced the lowest annual yields per acre. Thereafter, in the third cycle of tapping, density (a) improved in relation to the other densities although the actual yield declined considerably from the second cycle tapping. During the first four years of tapping the greatest annual production was from planting density (c) with 222 planted trees per acre. Subsequently, however, it was overtaken by the densest planting (e) which continued to lead until the high panel was opened in the twenty-sixth year from budding. The relatively slow start of production in the densest planting is in accord with the fact that it attains its maximum percentage of tappable trees some years later than the other planting densities.

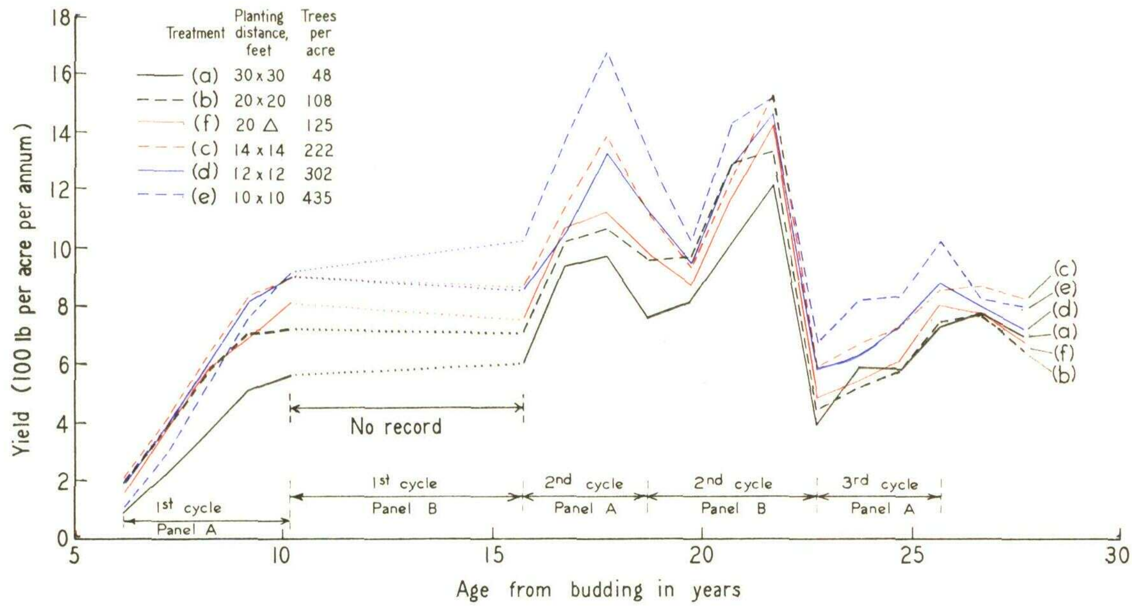

Figure 5. Effect of density of planting on annual yield of No. 1 RSS per acre.

The overall mean annual yield per acre and yield per tree for each planting density is shown in *Table 3*. Mean values for No. 1 RSS plus lump and scrap are derived from sixteen years recording and are therefore not directly comparable with the mean values for No. 1 RSS only, which derive from eighteen years recording. However, yields per acre per year are expressed below as percentages of those yielded by the control density (c), and it is clear that the relative yields of the various densities are not appreciably affected by the inclusion of lump and scrap. The question of the proportion of lump and scrap is discussed more fully later.

	(a)	(b)	(f)	(c)	(d)	(e)
Density	48	108	125	222	302	435
No. 1 RSS	76	87	88	100	97	108
No. 1 RSS plus lump and scrap	76	86	87	100	98	110

It is evident that there is a positive correlation between stand per acre and yield per acre, although systems (c) and (d) are reversed in rank.

As with yields per tree, yields per acre from the second cycle of tapping of both panels were generally greater than those obtained from the first and third cycle of panel A. The fluctuations in production in the post-war years demonstrate the effect of panel changes.

Proportion of lump and scrap. The amount of lump and scrap, expressed as a percentage of total yield (lb per acre per annum) and averaged over the 16 years for which complete records are available, is shown in *Table 4* for each planting density.

The annual variation, (not shown in the table), followed a similar pattern for each planting density in that percentage of lump and scrap was greatest in the first year of tapping and was followed by a clear decrease in the second and third years. The opening of each new panel on renewed bark was also associated with a high level of scrap production, with a decline in succeeding years.

The influence of planting density on the percentage of lump and scrap was not clear from an inspection of the data for individual years, but correlating the sixteen-year means

TABLE 3. MEAN YIELDS, IN POUNDS

Yield measurement		Trees per acre (a) 48	(b) 108	(f) 125	(c) 222	(d) 302	(e) 435	Standard error ± of a mean
Yield/tree/year:	No. 1 RSS only (1)	14.71	8.27	7.28	5.21	4.27	3.71	0.271
	inc. lump and scrap (2)	17.43	9.62	8.53	6.16	5.09	4.44	0.332
Yield/acre/year:	No. 1 RSS only (1)	657	755	759	863	838	930	29.7
	inc. lump and scrap (2)	773	874	883	1014	992	1116	34.5
Cumulative yield/acre: (3)								
	No. 1 RSS only	14472	16824	17145	19465	18991	21047	672.9
	inc. lump and scrap	16583	19187	19716	22595	22193	24529	766.7

(1) Averaged over 18 years recording of No. 1 RSS
(2) Based on only 16 years recording of No. 1 RSS plus lump and scrap
(3) Total yield per acre from 22 years tapping including estimates for unrecorded years.

TABLE 4. LUMP AND SCRAP AS A PERCENTAGE OF TOTAL YIELD, LB PER ACRE PER ANNUM

(Means of data for sixteen years of tapping)

Planting distance in ft	Trees per acre	Mean, %
(a) 30×30	48	14.4
(b) 20×20	108	14.6
(f) 20△	125	15.2
(c) 14×14	222	16.2
(d) 12×12	302	17.0
(e) 10×10	435	17.4
Mean		15.8

shown in *Table 4* with stands per acre gives a very significant correlation coefficient, ($r=+0.97$**), and the following regression equation: $y=0.0085x+14.04$

where y=percentage of lump and scrap

x=planting density, trees per acre

A similar equation is obtained if lump and scrap is expressed as a percentage of total yield when measured in terms of lb per tree per annum.

These equations demonstrate an increase in the percentage of lump and scrap with increased planting density. However, the magnitude of the effect, amounting to about 0.9% lump and scrap per 100 trees per acre, is small and certainly cannot be regarded as an influential factor in the choice of an optimum planting density.

Cumulative yields per acre. The loss of yield recording during the Japanese occupation means that precise cumulative yield records are not available up to the final year. Approximate figures have been derived, however, by estimating the yields per acre of the missing years by simple linear interpolation. Since the second panel of virgin bark would be expected to yield as well or better than the first panel of renewed bark, this interpolation almost certainly gives values which are too low. It is however difficult to introduce a more realistic estimation without also biasing the density effects. In any case, the effect of this underestimation on the comparison of

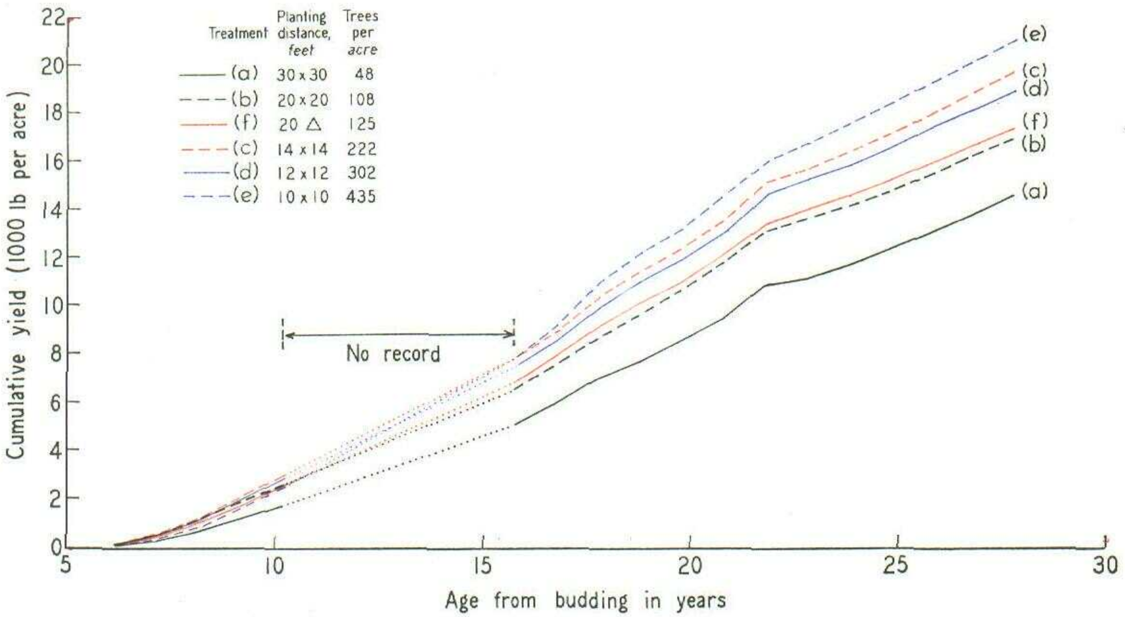

Figure 6. Effect of density of planting on cumulative yield of No. 1 RSS per acre.

cumulative production by different planting systems after twenty-two year tapping should be relatively small. The cumulative yields of No. 1 RSS are shown in *Figure 6.* A similar pattern was found for total rubber. Final cumulative yields per acre after 22 years' tapping are shown in *Table 3.*

Planting density (a) with a stand of 48 trees per acre has the lowest cumulative yield per acre at all stages, and after twenty-two years tapping its cumulative production (14,472 lb No. 1 RSS per acre) is only 74.3% of that obtained from the control density (c) (222 trees per acre) and 68.8% of that obtained from the densest planting (e). The cumulative yield of density (e) lags behind the control during the first few years but thereafter exceeds those of the other planting densities.

Cumulative yield per acre up to the final year is positively correlated with planting density, although densities (c) and (d) are reversed in rank. The cumulative yields for the whole period (see *Table 3*) are expressed below as percentages of the control density(c).

	(a)	(b)	(f)	(c)	(d)	(e)
Density	48	108	125	222	302	435
No. 1. RSS	74	86	88	100	98	108
No. 1 RSS plus lump and scrap	73	85	87	100	98	109

These relative cumulative yield values are in broad agreement with those of the previous table of observed relative yields per acre per annum. The minor discrepancies arise from estimation of unrecorded years in the cumulative figures.

Cumulative yields of No. 1 RSS per acre expressed as a percentage of control density (c) are illustrated in *Figure 7.* The graph for yields including lump and scrap is almost identical and is not reproduced here. Separate curves are shown corresponding to cumulative yields after 1, 5, 10, 16 and 22 years tapping. Relative yields per acre from the first year of tapping vary markedly with planting density; at this stage the highest yield per acre is produced by a planting density of 222 trees per acre (c), and the production from density (a), 48 trees per acre, or (e), 435 trees

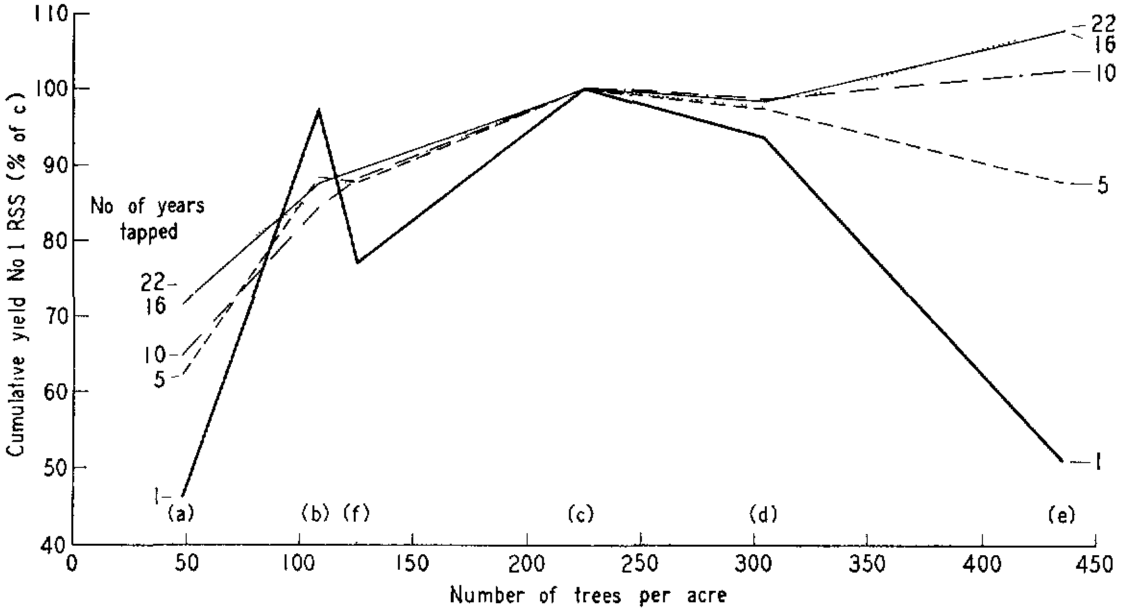

Figure 7. Effect of number of years in tapping on relationship between planting density and relative cumulative yields of No. 1 RSS.

per acre, is only about half this optimum. The differences between cumulative yields after five years tapping are less marked, particularly at the higher densities. The denser plantings are then beginning to overcome their initial handicap and the optimum density value is increasing. After ten years of tapping, the cumulative yields increase with planting density, but the trend is less pronounced at the higher densities and the cumulative yield at density (e) is only about 7% more than at density (c). Subsequently the shape of the relative cumulative yield curve undergoes comparatively small changes.

Hence the trial demonstrates that, despite a slow start, the cumulative yield of a dense planting of AVROS 50, tapped S/2.d/2.100%, will slightly exceed that of more conventional densities by the end of the economic life of the planting. In Part II of this paper it will be considered whether this additional crop from denser plantings is likely to compensate for the higher tapping costs.

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