Influence of Plot Sizes on Precision in Manuring Experiments on Hevea Brasiliensis

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An assessment of the effects of plot size on the precision of measurement of girth, girth increment and yield was made with data from experiments with pre-war and post-war mature trees and immature trees recently planted. The plot size as area and trees per plot (stand) did not influence the coefficient of variation (c.v.) of girth and girth increment significantly. The only useful regression equation derived from the study was for the c.v. of yield on plot characteristics as area and stand at the start of an experiment. Variations in plot error among experiments were more pronounced than annual or half-yearly recording variations within each experiment for girth, girth increment and yield. A nomogram is presented for quick assessment of significant margins of treatment differences for two to ten replications within an experiment.

Assignment of treatments to plots in field experiments follows pre-determined statistical designs, such treatments being compared eventually on the basis of plot variation. The margin for detecting treatment effects also depends on the magnitude of the plot variation and the number of replications for each treatment.

A study was made to assess the effect of plot characteristics on plot variation in relation to girth, girth increment and yield. Data were obtained from three categories of manuring experiments conducted by the Rubber Research Institute of Malaya for thirty years in various parts of Malaya, including its own Experiment Station at Sungei Buloh. This study was restricted to comparisons of treatment differences as influenced by plot characteristics. Though it is felt that the conclusions are generally applicable even for comparisons between clones, further work is necessary to confirm this hypothesis in the light of possible poaching and boundary effects.

Choice of plot sizes is important for controlling plot variations at a low level. Such variations are easily calculated in uniformity trials or in the absence of treatments of any sort. SMITH (1938) formulated an empirical equation for soil heterogeneity. PEARCE (1955) and FREEMAN (1963) further extended these ideas. NARAYANAN (1965) discussed the optimum number of trees adequate for recording in plots. PAARDEKOOPER (1966) summarised the results of uniformity trials to determine plot size and shape based on girth as the criterion for clonal comparisons.

METHODS

A critical examination of every past experiment to examine the efficiency of plot sizes would have been tedious; also there have been many changes in plot areas and planting densities over the years. Therefore only a representative selection of the experiments was studied:

Group A — 8 experiments on trees planted pre-war;

Group B — 11 experiments on trees planted after the war;

Group C — 20 experiments on recent plantings (immature at the time of measurement).

For each group, the c.v. of plot variation was examined as influenced by acreages and the number of trees. In Groups A and C, the trees per plot at planting and, in Group B, the stand at the start of the experiment after thinning, were utilised. To obtain the c.v. of plot variation, the mean squares associated with plot error of the relevant design was used.

COMMUNICATION 430

Group A (Pre-war Trees)

The eight experiments studied are outlined in *Table 1*, with details of their statistical design. The areas were planted in 1937, and budded after one or two years. In the experiment at Sungei Kawang Estate, budded stumps were planted. All experiments commenced from the time of planting and continued well into maturity of the trees involved.

The planting systems were either 15.5′ × 15.5′ or 22′ × 11′. The plot size generally exceeded one acre, but two experiments were on half-acre plots. To eliminate border effects, two rows at the ends were omitted from recording, so were the two trees at either end of each row. Yield per plot was recorded in grams per tree per tapping by cup coagulation on two days in each calendar month. These values were averaged over twelve months to obtain the plot yield for one year. The data were analysed statistically and mean c.v. values were calculated. Although girth and girth increment have also been obtained, their c.v. values are not included in this study.

Table 2 gives the mean c.v. for yield over the period of recording and the plot size in acres and stand. The average for the eight experiments is 11.62 and there is no indication of the coefficient of variation depending on plot characteristics.

Group B (Post-war Mature Trees)

Eleven experiments were chosen under this category, all selected to contain only clones and not seedling material, which are less favourable for higher yields and are also more

TABLE 1. DETAILS OF PRE-WAR MATURE TREE EXPERIMENTS (GROUP A)

Description	Planted/ budded	Planting distance	Clones/seedlings	Statistical design
Kempas	'37/'39	22′ ×11′	Tjir 1, Pil B 84	Manuring expt. N and P, in 5 replications with blocks of 8 plots each. (Time of commencing manuring).
Muar River	'37/'39	15.5′×15.5′	PB 86, Pil B 84	4×2×2 factorial 4 levels of P, 2 qualities of P and presence or absence of N. In two replications involving 2 clones in blocks of 8 plots each.
North Labis	'37/'39	15.5′×15.5′	PB 86, Tjir 1	2^3 factorial NPK, for 2 clones in 5 replications with blocks of 8 plots each.
Rengam	'37/'38	22′ ×11′	Tjir 1, PB 86, Pil B 84	6 treatment series of 2^3 NPK, in 6 replications with blocks of 6 plots each.
Sepang	'37/'39	16′ ×15′	PB 86, Pil B 84	Phosphate manuring expt. 4 blocks of 6 plots and also 2 blocks of 4 plots each. N and 2 qualities of phosphate.
Sungei Kawang	'37	22′ ×11′	Tjir 1, PB 86, Pil B 84	6 treatment series of 2^3 NPK, in 6 replications as Latin square of 6 plots each.
Wardieburn A	'37/'38	22′ ×11′	Tjir 1	3^2 factorial NP, 5 blocks of 10 plots each. An extra observation plot included in each block.
Wardieburn B	'37/'39	22′ ×11′	Tjir 1	2^3 factorial NPK, 5 blocks of 8 plots each.

Note: All these experiments commenced from the time of planting and continued right through immaturity and maturity.

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TABLE 2. PRE-WAR MATURE TREE EXPERIMENTS (GROUP A) — PLOT CHARACTERISTICS, MEAN COEFFICIENTS OF VARIATION FOR YIELD AND THE PERIODS OF DATA

Description	Plot size (acres)	Planting (points/plot)	Density at planting (trees/acre)	Yield, mean c.v. over years (%)	Period available
Kempas	1.00	180	180	11.26	'48 – '59
Muar River	1.24	225	181	10.79	'55 – '60
North Labis	1.00	180	180	10.41	'49 – '59
Rengam	1.50	270	180	14.42	'48 – '51 '52 – '59
Sepang	1.25	226	180	10.49	'49 – '58
Sungei Kawang	1.50	270	185	10.74	'49 – '59
Wardieburn A	0.50	90	180	13.26	'48 – '59
Wardieburn B	0.50	90	180	11.58	'48 – '59
Mean of experiments	1.06	191	181	11.62	

variable regarding growth (*Table 3*). The trees were planted and budded between 1948 and 1953, except on Swee Lam where trees were planted in 1958. The planting systems were square, rectangular or hedge plantings. The planting density ranged between 162 and 193 trees per acre, except on Johore River Estate with a planting density of 280 trees per acre. Thinning was on average 74% during immaturity. The plots varied in size between 0.2 and 1 acre. The number of trees per plot at the start of experiment, together with the plot characteristics and the c.v.'s for girth, girth increment and yield are given in *Table 4*.

As in the case of pre-war experiments, one border row on either side and two trees from each end were omitted in recording girth and yield data. Thus, only 40 to 50 per cent of the trees were recorded. In hedge plantings with a row width of 60 feet, only two trees from each end in rows were excluded for border effects. For recording of yield, the latex of trees involved were cup-coagulated on two tapping days in a calendar month and plot values were obtained in grams per tree per tapping. In certain experiments, analysis of girth increment and yield indicated reduction in error mean squares when adjusted for pre-treatment girth and yield respectively during the initial years. In this study, however, the unadjusted error mean squares have been used throughout.

Table 7 gives the correlation coefficients in this group of experiments between the plot characteristics—acreage and stand per plot—and c.v. of girth, girth increment and yield. When the original data are transformed to logarithms, the correlation coefficients are only of similar magnitude (*Table 7*). Plot acreage shows a greater influence on the c.v. of yield than trees per plot at the start of the experiment. The other correlation coefficients are relatively unimportant.

The linear regression relationship for c.v. of yield on plot acreage and stand per plot are given in *Figures 1* and *2* respectively. Using the logarithms and adjusting the resultant equation to pass through the overall means of c.v. for

TABLE 3. DETAILS OF POST-WAR MATURE TREE EXPERIMENTS (GROUP B)

Description	Planted/ budded	Planting distance	Clones/seedlings	Statistical design and present status
Chemor United	'51	15′×15′	PB 86 budded stumps	3^3 factorial NKMg, single replication in 3 blocks of 9 plots each. (discontinued)
Edinburgh	'49/'50	16′×16′	PB 86	2^5 factorial NPMgCu, type of P, single replication, 4 blocks of 8 treatments each. (discontinued)
Harpenden	'50/'51	22′×11′	G1	2^5 factorial NPKCu, type of P, single replication, 4 blocks of 8 treatments each. (discontinued)
Johore River	'52/'53	23′×6.75′	Tjir 1	3^3 factorial NMgMn, single replication in 3 blocks of 9 plots each.
Kepong	'50/'51	22′×11′	RRIM 501	2^4 factorial NPKMg trial, in 3 replications with each of the blocks containing 8 plots each. (discontinued)
Seafield	'49/'50	20′×12′	PB 86	2^5 factorial PKMgMn, type of P, basic N, single replication, 4 blocks of 8 treatments each. (discontinued)
Sepang	'48/'49	22′×11′	PB 86	3^3 factorial NPK, single replication in 3 blocks of 9 plots each. (continued with plots subdivided for presence and absence of Magnesium)
Sungala	Nov. '48/ Jan. '51	22′×11′	PB 86	3^3 factorial NPK, single replication in 3 blocks of 9 plots each.
Swee Lam	Feb. '58/ Sept. '58	22′×10′	LCB 1320	3^3 factorial PKMn, single replication in 3 blocks of 9 plots each.
R.R.I.E.S. A	'50/'51	66′×4′	RRIM 501, PR 107, Tjir 1	3^2 factorial Copper sulphate, Muriate of Potash in six replications. (discontinued)
R.R.I.E.S. B	'49/'50	60′×4.5′	Tjir 1, BR 2, PB 49, AVROS 157, RRIM 509	3^3 factorial NPK, single replication in blocks of 9 plots each. (discontinued)

yield and plot acreages (or trees per plot) the following equations are derived.

$$y = 10.30x^{-0.2727} \quad \ldots(1)$$

$$y = 34.17z^{-0.2410} \quad \ldots(2)$$

where y, x and z denote the estimate of c.v. for yield, plot size in acres and number of trees per plot at start of experiment respectively.

The above equations on squaring would provide the dependence of variance on plot size on the model Fairfield Smith enunciated with heterogeneity coefficients below unity.

$$V_s = \frac{V_1}{s^b} \quad \ldots(3)$$

where V_s represents variance between plots of size s (acreage or number of trees)and V_1 the variance for plots of unit size and b denotes the heterogeneity coefficient. The heterogeneity

TABLE 4. POST-WAR MATURE TREE EXPERIMENTS (GROUP B) — PLOT CHARACTERISTICS, MEAN COEFFICIENTS OF VARIATION AND PERIODS OF DATA

Description	Plot size		Density		Thinning at start (%)	Mean c.v. over years (%)			Records available‡		
	acre	trees at start	at planting	at start		Girth	Girth increment	Yield*	Girth	Girth increment	Yield
Chemor United	0.47	75	193	160	83	3.39	16.67	13.18	'62, '65, '66 (3)	'62–'66 (4)	'62–'66 (4)
Edinburgh	0.49	53	170	109	64	2.48	16.16	8.60	'60 (1)	'60–'63 (3)	'60–'63 (3)
Harpenden	0.62	73	180	116	64	4.90	10.82	16.03	'60 (1)	'60–'62 (2)	'60–'62 (2)
Johore River	0.50	77	280	154	55	2.33	10.48	11.62	'61 (1)	'61–'63 (2)	'61–'63 (2)
Kepong	0.80	126	181	158	87	3.83	22.57	12.57	'59 (1)	'59–'62 (3)	'58–'62 (4)
Seafield	0.98	132	180	135	75	3.59	24.18	8.17	'60 (1)	'61–'63 (2)	'60–'63 (3)
Sepang	1.00	124	180	124	69	6.10	18.70	9.45	'58, '63, '66 (3)	'58–'66 (7)	'58–'63 (5)
Sungala	0.82	107	180	130	72	4.62	12.89	7.45	'58 (1)	'58–'63 (5)	'57–'63, '64–'65 (7)
Swee Lam†	0.69	112	180	163	91	2.18	6.86	11.19	'62, '66 (2)	'62–'66 (4)	'65 (1)
R.R.I.E.S. A	0.19	28	181	147	81	5.24	19.02	14.24	'58, '63 (2)	'58–'63 (5)	'58–'64 (6)
R.R.I.E.S. B	0.61	73	162	120	74	6.50	15.71	14.89	'57, '63 (2)	'57–'63 (6)	'57–'63 (6)
Mean of experiments	0.65	89	188	138	74	4.10	15.82	11.58			

* The yearly c.v. values are used unadjusted by covariance analysis.

† For this experiment, yield is analysed only over one year data.

‡Number of records in brackets.

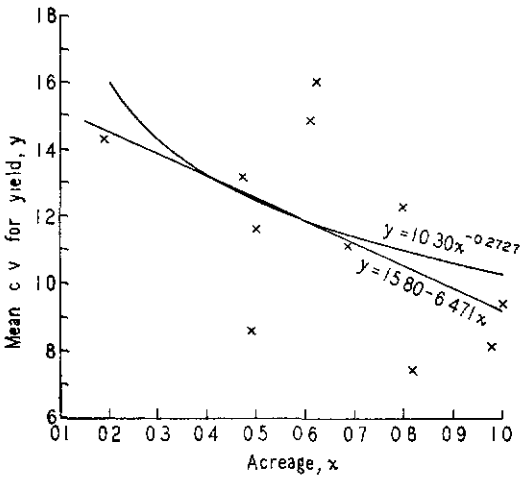

Figure 1. The relationship of coefficient of variation for yield on plot acreage.

coefficients from Equations 1 and 2 could be calculated as 0.54 and 0.48 respectively.

In *Figures 1* and *2*, the above equations are plotted along with the original data and inspection of the curves shows that these Equations 1 and 2 represent the relationship more satisfactorily than linear regression lines.

Analysis of all c.v. values from the various recordings (mostly annual) of all experiments were carried out to evaluate the resulting two components of variation given in *Table 8*. One of them gives the standard deviation for the annual values of c.v. to differ from the mean coefficient of variation of a chosen experiment. The other component shows in terms of standard deviation how c.v. means of experiments vary around the overall mean coefficient of variation. Of course, varying number of years of records were available from different experiments and the estimate of s.d. given is a pooled result. Relative to the benefits on reduction in plot error one derives from covariance analysis (NARAYANAN, 1966), such benefits are not to be over-emphasised in the choice of plot size.

The variation is significantly higher among experiments than among yearly differences. To estimate ultimately as to how at any site or experiment the annual c.v. values would vary, the total standard deviation is shown (*Table 8*) adding the components for annual variation and experimental variation. Relative to the overall mean c.v. values of all experiments, total s.d. values are quite high.

Group C (Experiments on Recent Plantings)

Twenty experiments were included under this category; the details of the designs, plot characteristics and mean c.v. values are given in *Tables 5* and *6*. These experiments, which included seedling trials, were started later than 1953 in square, rectangular and hedge planting systems. The density ranged between 150 and 242 planting points per acre and plot sizes were on the average below half an acre. Of these twenty experiments, only nine are still continued at present with or without modifications.

As in post-war mature experiments, border trees were not recorded so that the recorded trees were only 40 to 50 per cent of the total planting points. During the early stages of growth, girths were recorded generally at half-yearly intervals when growth rate was fast and later at yearly intervals. Thus girth increment accordingly refers to half-yearly intervals initially and later to yearly intervals. In analysis

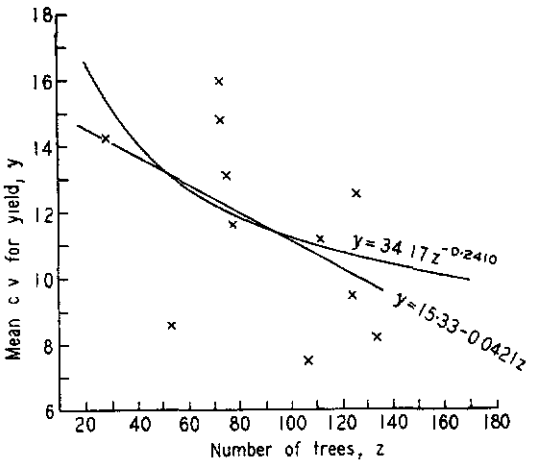

Figure 2. The relationship of coefficient of variation for yield on trees per plot at start of experiment.

TABLE 5. DETAILS OF RECENT IMMATURE TREE EXPERIMENTS (GROUP C)

Description	Planted/ budded	Planting distance	Clones/seedlings	Statistical design and present status
Bradwall	'58/'59	24′×10′	RRIM 623	Cover plant expt., 4 covers, 2 levels of fertiliser, 2 methods of application, 3 replications of split plot design with covers in main plots.
Bukit Rotan	'54	20′×12′	PB 86 budded stumps	2^4 factorial NPK, methods of application, in 3 replications, blocks of 8 plots each. Modified in 1959 to include application of Mg. (discontinued)
Devon A	'54/'55	14′×14′	RRIM 501	3^3 factorial NPK in frequency of application, single replication in 3 blocks of 9 plots each. (discontinued)
Devon B	'54	14′×14′	PB further proof seedlings	Different methods of application of fertilisers in sub plots, 2 weeding schemes in main plots, 4 replications of split plot design. (discontinued)
Devon C	'54/'55	14′×14′	RRIM 501	3 treatments in main plots with holing/not holing in sub plot, 5 replications of a split plot design. (discontinued)
Effingham	'55/'56	20′×12′	PB 86	2^4 factorial NPK, method of applications to cover or rubber, 3 replications in blocks of 8 plots each. (discontinued)
Jugra	Jan. '58/ Nov. '58	15′×15′	PB 5/63	2^5 factorial NPKMg, type of N, single replication in 4 blocks of 8 plots each. (discontinued)
New Labu	'54	17′×17′	PB 86 budded stumps	2^4 factorial NPK, method of applications to cover or rubber, 3 replications in blocks of 8 plots each. (discontinued)
Selangor River A	'54	15′×12′	Tjir 1 selfed seedling	2^4 factorial NPK, method of applications to cover or rubber, 3 replications in blocks of 8 plots each. (discontinued)
Selangor River B	'57/'59	24′×10′	GT 1	Cover plant expt., 4 covers, 2 levels of fertiliser and 2 methods of application, 4 replications of split plot design with covers in main plots. Altered in 1964.
Sepang	'57	30′×8′	G.G. 1. stumps	Cover plant expt., 4 covers, 2 levels of fertiliser and 2 methods of application, 3 replications of split plot design with covers in main plots. Altered in April 1963.
R.R.I.E.S. A	'56/'58	22′×11′	RRIM 603	6 treatments of 3 cover plants and 2 methods of applications of fertiliser, 4 replications. (discontinued)
R.R.I.E.S. B	'51/'53	60′×4′	RRIM 501	3^3 NPK factorial in 3 replications each of 3 blocks with 9 plots. (discontinued)
R.R.I.E.S. C	'51/'53	60′×4′	RRIM 501	3^3 frequency of application of NPK, single replication in blocks of 9 plots each. (discontinued)
R.R.I.E.S. D	'55	22′×9′	Tjir 1 clonal seedling	Planting techniques expt. 3×2×2 in 2 replications, 3 rates of mixture, 2 basket sizes, Mg presence and absence. Altered from 1964 to include sub-treatments of presence and absence of Mn in original plots.
R.R.I.E.S. E	'57	24′×8′	Tjir 1 selfed seedling	Cover plant expt., 4 covers, 2 levels of fertiliser, 2 methods of application, 3 replications of split plot design with covers in main plots.
R.R.I.E.S. F	'57	24′×8′	Tjir 1 selfed seedling	3^3 factorial NPK, single replication in 3 blocks of 9 plots each. Altered from 1963 so as to subdivide each plot into 2 — one with manuring continued and the other without manuring.
R.R.I.E.S. G	'57/'59	24′×10′	LCB 1320, GT 1, PB 86	2^4 factorial NPKMg, in 3 clones, 2 replications for each clone in blocks of 16 plots each. Altered in 1965 to exclude PB 86 due to wind damage and plot made to include a third level for NPKMg.
R.R.I.E.S. H	'59/'60	22′×11′	RRIM 513	3^3 factorial NKMg, single replication in 3 blocks of 9 plots each.
R.R.I.E.S. I	'59/'60	22′×11′	RRIM 605	3×3×2 factorial NPCa, in 2 replications of 6 blocks with 6 plots each.

TABLE 6. RECENT IMMATURE TREE EXPERIMENTS (GROUP C) — PLOT CHARACTERISTICS, MEAN COEFFICIENTS OF VARIATION AND PERIODS OF DATA

Description	Plot size (acre)	Planting (points/ plot)	Density at planting (trees/acre)	Mean c.v. over years (%)		Records available‡	
				Girth	Girth increment	Girth	Girth increment†
Bradwall	0.50	90	181	2.47	6.34	'60 – '64 (6)	'60 – '64 (6)
Bukit Rotan	0.46	84	181	4.28	6.65	'57,'60 (2)	'57 – '63 (7)
Devon A	1.00	222	224	6.32	8.45	'57,'62 (2)	'57 – '63 (8)
Devon B	0.27	60	222	5.03	4.75	'56 (1)	'56 – '59 (5)
Devon C	0.43	96	222	2.24	3.81	'57,'62 (2)	'56 – '62 (6)
Effingham	0.50	91	182	6.98	8.14	'58,'60,'63 (3)	'58 – '63 (7)
Jugra	0.37	72	193	8.36	5.21	'60 (1)	'60 – '63 (5)
New Labu	0.56	84	150	3.54	5.19	'57,'61 (2)	'58 – '61 (4)
Selangor River A	0.50	121	242	3.14	4.94	'57,'60,'62 (3)	'57 – '59, '60 – '62 (4)
Selangor River B	0.61	112	181	3.06	5.06	'60,'62–'64 (4)	'60 – '64 (7)
Sepang	0.61	110	181	5.14	9.22	'59,'61–'64 (5)	'59 – '64 (8)
R.R.I.E.S. A	0.30	54	180	4.89	10.12	'59,'61,'62, '64 (4)	'59 – '64 (6)
R.R.I.E.S. B	0.25	45	180	4.72	7.56	'54,'64 (2)	'54 – '62 (8)
R.R.I.E.S. C	0.20	36	180	8.24	5.61	'54 (1)	'54 – '59 (7)
R.R.I.E.S. D	0.50	112	220	5.36	5.66	'57 (1)	'57 – '61 (6)
R.R.I.E.S. E	0.40	90	226	4.20	8.42	'59,'61–'64 (5)	'59 – '62, '63 – '64 (8)
R.R.I.E.S. F	0.66	150	226	4.32	6.97	'59 (1)	'59 – '63 (8)
R.R.I.E.S. G	0.33	60	181	4.26	8.66	'60,'62 (2)	'60 – '63 (6)
R.R.I.E.S. H	0.50	91	181	3.28	4.32	'61,'65 (2)	'61 – '65 (7)
R.R.I.E.S. I	0.50	91	181	4.60	6.66	'61,'66 (2)	'61 – '66 (9)
Mean of experiments	0.47	94	196	4.72	6.59		

†For girth increments of immature trees half-yearly recordings are as frequently obtained as yearly recordings. The trials at R.R.I.E.S. are generally recorded for girth increment analysis over six months intervals.
‡Number of records in brackets.

of variance and for averaging c.v. values no account of this effect was made, because the half-yearly results were similar to yearly c.v. values for any particular experiment.

Correlation coefficients for association between plot characteristics of acreage or trees per plot and c.v. values for girth and girth increments based on twenty experiments are given in *Table 7*. All these coefficients are not significant and hence there is no use in calculating heterogeneity coefficients.

The two components of variation, one referring to yearly (or half-yearly) variation within any particular experiment and the other to experimental variation from the overall mean c.v. value are given in *Table 8*. Both girth and girth increment show significant experimental component and total variation includes the two components. The standard deviation from the total variation provides a measure as to how annual or half-yearly c.v. values vary from any experiment around the true experimental coefficient of variation.

DISCUSSION

Girth is a valid measure of tree growth, and it is not as variable as girth increment or yield. The nature of girth increment as a measure of growth is questionable. Only if the girths of trees are similar at the beginning of a period, girth increments are comparable in terms of growth. For experiments on immature trees, girth increments are relatively less variable compared with experiments on mature trees and treatments are compared in terms of girth increments as a rough guide.

The relationship of girth and girth increment variations on plot characteristics could not be

TABLE 7. CORRELATION COEFFICIENTS

Description	Post-war mature tree experiments			Recent immature tree experiments	
	Girth	Girth increment	Yield	Girth	Girth increment
(a) Original values					
Plot size (acres)	0.1423	0.2524	−0.5384 (P<0.1)	−0.1371	0.1047
Planting points (number)	−0.0561	0.2147	−0.4863	−0.1046	0.0769
Correlation between plot size and planting points	0.936***			0.952***	
(b) Logarithms for both properties					
Plot size (acres)	0.0285	0.0285	−0.4884	−0.2374	0.0548
Planting points (number)	−0.0902	−0.0186	−0.4292	−0.2444	−0.00014
Correlation between plot size and planting points	0.953***			0.955***	

TABLE 8. COMPONENTS OF VARIATION

Description		Post-war mature tree experiments			Recent immature tree experiments	
		Girth	Girth increment	Yield	Girth	Girth increment
Year to year	s.d.*	±1.228	±4.216	±1.917	±1.511	±2.638
Experiment to experiment	s.d.	±1.272	±4.212	±2.932	±1.191	±1.431
Total	s.d.	±1.77	±5.96	±3.50	±1.92	±3.00
Mean c.v. values		4.10	15.82	11.58	4.72	6.59
Mean + total s.d.		5.87	21.78	15.08	6.64	9.59

*For girth increments of immature tree trials half-yearly recordings were as frequently obtained as yearly recordings.

proved at significance level in this study. Regarding c.v. of yield, regression equations are evaluated even though significance level is bordering only 10%. The experiments had different planting materials, fertility variations and recorded areas. Such sources might have contributed to the camouflaging of any such relationship which might be expected under controlled conditions at a particular site. Out of 11 and 20 experiments in the last two categories, only 2 and 9 experiments respectively were selected from Sungei Buloh, the others being chosen from different parts of Malaya.

Consideration of the relationship of c.v. on plot characteristics under similar planting points per acre did not improve the significance level of correlation coefficients. For this purpose, examination of data for the common density of 180 trees per acre was available from many experiments. In recent plantings, a few with densities higher than 220 per acre were also utilised in this investigation.

The general consideration of components of variation in *Table 8* indicates how serious is experimental variation in relation to yearly or half-yearly variation in c.v. of statistical analysis at any recording time for girth, girth increment and yield. If it is argued that c.v. distribution is non-Gaussian and is skewed to the right, it is better to utilise the mean c.v. and higher values in planning experiments. In this context the s.d. of total variation is added to the mean c.v. (*Table 8*).

A nomogram for selecting the number of replications for future experimental lay-out is given in *Figure 3*. An assumption of four treatments in a trial as in randomised block design is not very restrictive to arrive at a suitable degree of freedom for error mean squares. The formula used to derive the significant (at 5% level) margins for treatment differences is given by COCHRAN AND COX (1957):

$$\delta = \frac{\sqrt{2}\,(t_1 + t_2)}{\sqrt{r}}\,\sigma$$

where δ = true difference that is desired to detect as per cent of mean,

σ = true standard error per plot expressed as per cent of mean,

r = number of replications,

t_1 = significance value of t in the test of significance for two-tailed tests,

t_2 = significance value of t in the ordinary t table for the probability P_2 where $P = 1 - (\frac{1}{2}) P_2$

and P is the confidence level or chance of detecting such differences. The degrees of freedom available for error, which is $3(r - 1)$, are used for t_1 and t_2.

In *Figure 3*, along the coefficient of variation axis are marked the mean c.v. values of girth, girth increment and yield. In addition to these values there are marked the corresponding values of mean c.v. plus the s.d. of total variation (*Table 8*). The regression equation of the c.v. of yield on plot size is incorporated. From any chosen level of plot acreage (or number of trees per plot at start of experiment) a perpendicular drawn to the axis of c.v. values gives at its intersection with the latter the regression estimate of mean c.v. (as referred to in Equation 1 or 2). Thereafter this mean c.v. value or alternately with the addition of total s.d. is to be used.

For confidence levels of 50% and 80% (*i.e.*, $P = 0.50$ or 0.80) there are two pairs of

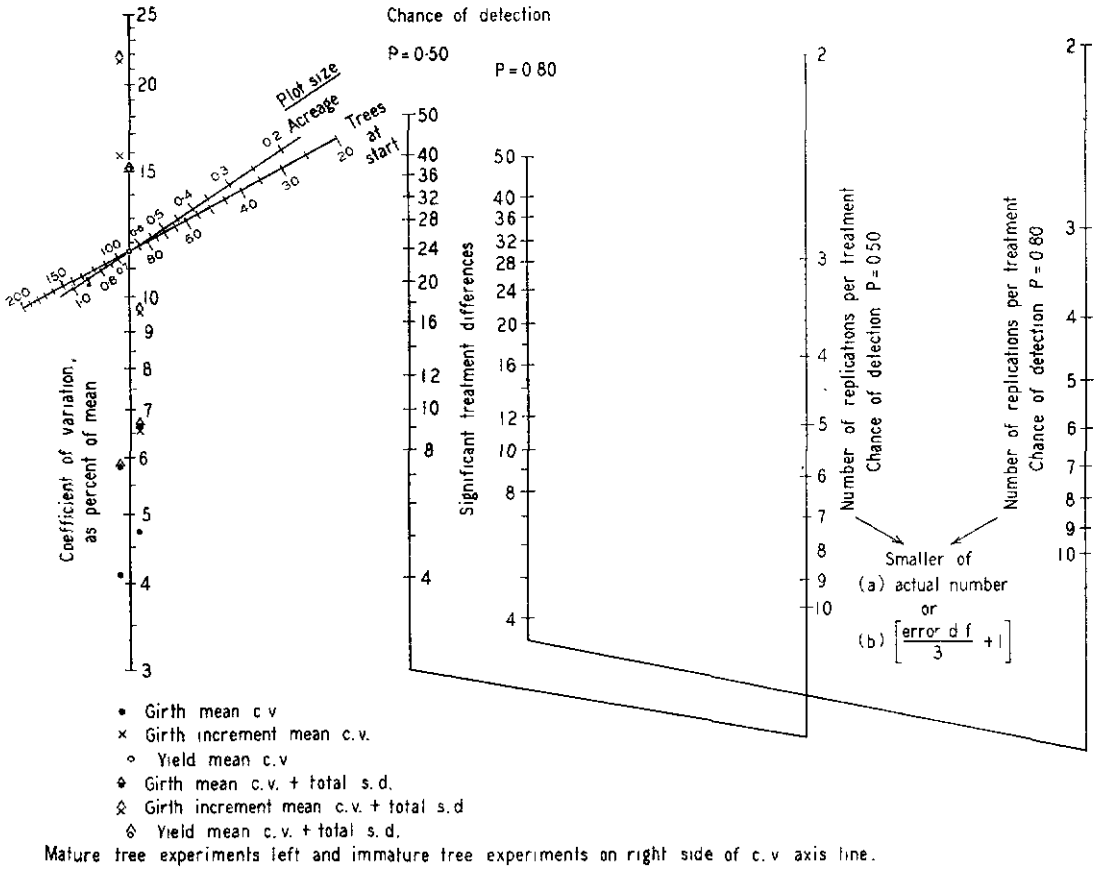

Figure 3. Nomogram for estimation of significant margin for treatment differences (at 5% level)

lines joined together. One of the pair gives the replication per treatment, which is aligned with the c.v. for any property like girth, etc. The other line of the pair where the above line intersects, gives the distinguishable difference between two treatments significant at 5% level; such conclusive evidence established in P% cases.

If any factorial experiment (3^3 or 2^5) is to be conducted in a single replication, the number of effective replication for a treatment combination is quite problematical. As a conservative estimate it is suggested to use for the number of replications the smaller of either (a) the actual replications of that treatment combination ignoring any levels of other factors or (b) estimated replication utilising the error degrees of freedom equated to three times the replication minus one [*i.e.*, Error d.f. $= 3\,(r - 1)$].

CONCLUSIONS

The coefficients of variation associated with girth, girth increment and yield were examined for the influence of plot characteristics of acreage and number of planting points. A strong indication for the relationship of c.v. for yield on plot characteristics led to the estimation of the regression relationship and the heterogeneity coefficient. The predicted c.v. for yield from the regression equation is preferred to the mean c.v. of all trials in planning future experiments. In terms of plot error the experimental variations were quite high relative to yearly (or half-yearly) variations within a given experiment. A nomogram is constructed to determine, for various replications in the range two to ten, true treatment differences which can be proved at significance level of 5%.

ACKNOWLEDGEMENT

The author acknowledges the help of the Soils Division and the computers of the Statistics and Publications Division in enabling this study. Thanks are also due to Mr E. Pushparajah of the Soils Division for discussions and helpful scrutiny of the paper.

Statistics and Publications Division
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Kuala Lumpur *July 1968*

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