Optimum Number of Trees in Tapping Experiments on Hevea Brasiliensis I. Half Spiral Alternate Daily Tapping with and without Stimulation

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Daily yields of three clones have been studied to assess their variations under the S/2.d/2.100% system. The variations did not show any pattern with seasons or with the application of yield stimulant. Based on the distributions of the coefficients of variation of the Mean (c.v.m.) for different clones, the minimum number of trees for accurate estimation of treatment Means—and for distinguishing treatment differences—have been derived. This minimum was found to be 50 trees. The distribution of single tree yields was somewhat skew, hence the grouping of eight or more trees as a unit or plot has been found to be desirable for achieving normality of distribution. Variation 'between trees' is more pronounced than variation 'between days' in any month, thus the recording of yields can be restricted to one or two days a month to obtain an accurate estimation of the monthly treatment Means.

In planning any experiment, an assessment of the natural variation of the population is necessary for determining the pattern and degree of replication required for estimating Means and for detecting differences of a pre-determined magnitude. In the case of rubber, the variation in daily yields of trees can involve the tapping systems, the clones, sites, seasons, the application or absence of yield stimulants and other considerations. In this study, the number of trees per plot, the replication per treatment and the intervals at which samples are taken are considered for only one tapping system, i.e. S/2.d/2.100% with and without stimulation. The investigations have been made on the basis of the daily yield records of selected clones in some tapping experiments and of individual tree yields for 300 trees of clone PB 86 in one task on one day of tapping.

EXPERIMENTAL

In each tapping experiment, 48 trees or replicates (a single tree being taken as a unit) had been taken for the tapping treatments studied. In two of the experiments, 15 tapping treatments (e.g. S/2.d/2.100%, S/2.d/3.67% without or with stimulation at various intervals) were compared on Panel B of clones PR 107 and PB 86; in the third experiment, 38 tapping treatments were compared on Panel A of clone RRIM 605. In the Panel A experiment, the experimental area was in two blocks, each containing half the number of trees involved in each tapping treatment. Allocation of individual trees to the different treatments was based on either the yield or the girth of the trees. Thus in Panel B experiments, the yields (for about a month on the S/2.d/2.100% system) of 720 trees of each clone were arranged in descending order and the 15 trees with the highest yields were assigned at random to the 15 treatments, the next 15 trees assigned similarly and so on. In the Panel A experiment, the same method of allocation was followed on the basis of girth at a particular height, but the allocation was made separately for each block. The procedure aimed to eliminate initial (or pre-treatment) girth or yield differences from the post-treatment yield comparisons.

The tapping schedule for each tree of the same treatment was determined similarly by listing all the trees of the group in order of yield or girth, dividing the list in accordance

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with the length of the interval between tappings and randomising within each sub-division. Thus, the 48 trees of a group being tapped alternate daily in the Panel B experiments were divided into 24 pairs, the 24 trees to be tapped on the same day being chosen at random from the pairs. In the Panel A experiment, the two blocks were treated independently in making the selection, 12 trees being chosen from each block for tapping on the same day.

Data

Daily yield records of trees tapped on the S/2.d/2.100% system with and without stimulation have been examined for the following experiments during the specified periods:

The Clone PR 107 (Panel B) experiment for one year (April 1965—April 1966).

The Clone PB 86 (Panel B) experiment for 7 months (May—December 1965).

The Clone RRIM 605 (Panel A) experiment for one year (May 1965—May 1966).

The examination covered non-stimulation and bi-monthly and half-yearly stimulation in the Panel B experiments and non-stimulation and half-yearly stimulation in the Panel A experiment.

RESULTS

Number of Trees for Accurate Estimation of a Daily Tapping Treatment Mean

For each of the three clones, the Means, standard deviations and coefficients of variation (c.v. $= \frac{\text{s.d.}}{\text{mean}} \times 100$) were obtained from the daily yield records of the 24 trees tapped each day in each treatment group. The coefficients of variation of the Mean (c.v.m.) were also calculated by dividing the different c.v.'s by the square-root of the number of observations (n) on which the Means are based (here n = 24). *Figures 1* and *2* show, for the three treatments, the daily Means and the daily c.v.'s of the 24 trees for one year for the PR 107 data. It can be seen from *Figure 1* that the daily Mean yields show a distinct seasonal variation coupled with a marked response to stimulation. The daily c.v.'s of the 24 trees (for each of the two groups), on the other hand, do not show any pattern of variation with season or with stimulation (*Figure 2*). The daily variation in c.v. throughout is in the range of 30 to 65%. The daily Means of the 24 trees show no association or relation with corresponding daily c.v.'s. Hence they can be considered as a random sample from the population of c.v.'s. Similar results are obtained for the PB 86 and the RRIM 605 data. For the PB 86, the daily variation in c.v. is between 20 and 40%. For the RRIM 605, the c.v.'s vary more erratically, ranging between 25 and 60%.

Frequency distributions of the observed c.v.m.'s of the daily yield records of the 24 trees have been determined in each of the cases and for each of the clones and these are listed in *Table 1*. Thus for the PR 107 data, the c.v.m.'s vary between 5.5 and 11% for non-stimulation; between 6 and 14% for bi-monthly stimulation and between 5.5 and 12% for half-yearly stimulation. The range of variation in daily c.v.m.'s is somewhat narrower (between 3.5 and 11%) with the PB 86 experiment in all the three cases. However, for the RRIM 605 experiment, the c.v.m.'s vary more widely, lying between 5 and 16% for non-stimulation, between 4 and 14% for half-yearly stimulation. *Figure 3* shows the observed frequency histograms of the daily c.v.m.'s for each of the treatments with the PR 107. The distributions appear symmetrical in all cases.

For normal distribution, we have

$$P\{|\bar{x}-a| \leqslant \frac{k\sigma}{\sqrt{n}}\} = \alpha$$

i.e. $$P\{|\bar{x}-a| \leqslant k(\text{c.v.m.})\,\bar{x}\} = \alpha \qquad \ldots(1)$$

where P denotes the probability
α is the confidence coefficient
$\bar{x}$ is the sample Mean
a is the true Mean
$\bar{x} - a = d$ is termed as the accuracy
σ is the standard deviation,
c.v.m. is the coefficient of variation of the Mean
and k is a constant, depending on α.

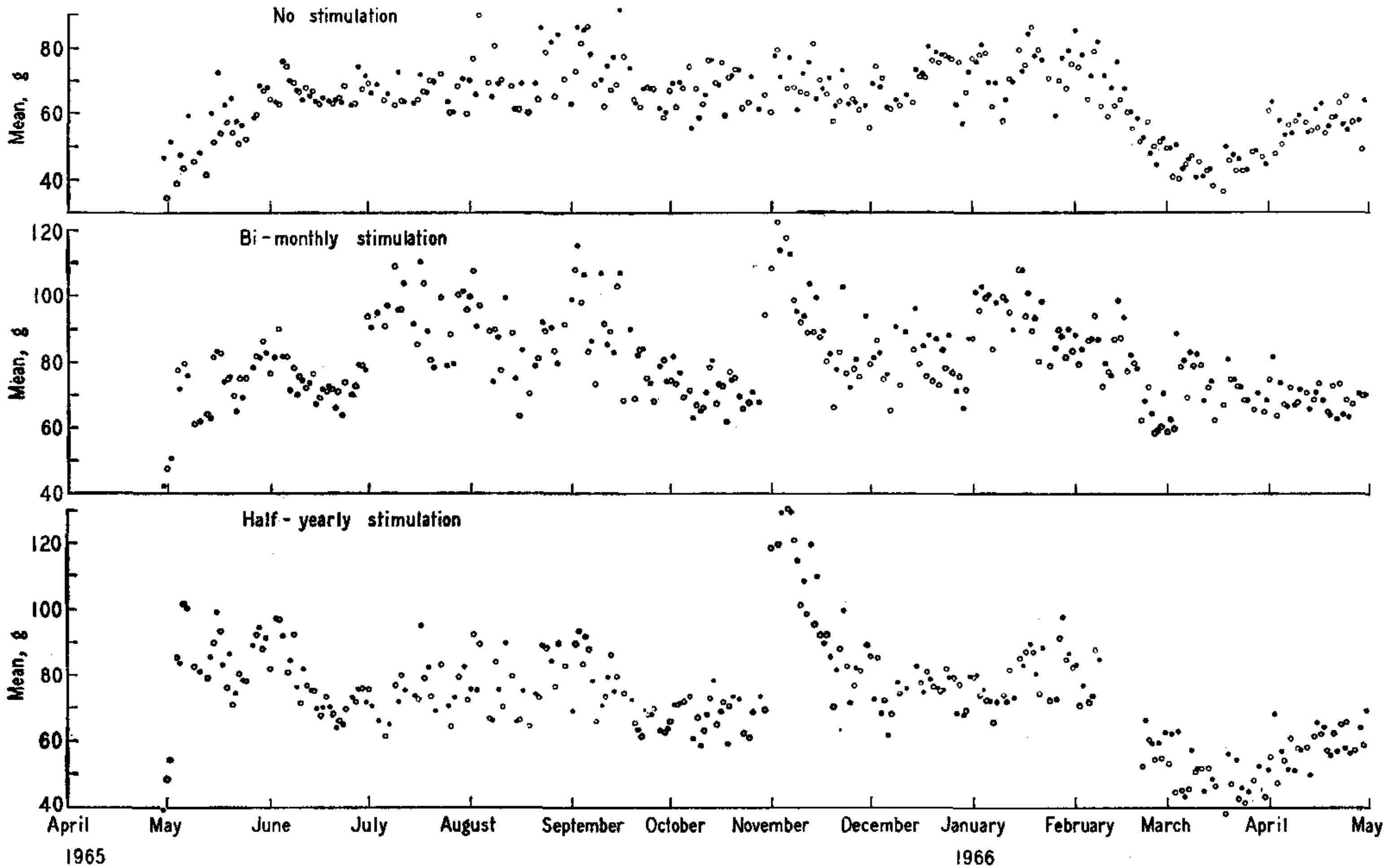

Figure 1. Means of daily yield records of 24 trees for the three treatments—Clone PR 107: S/2.d/2.100%.

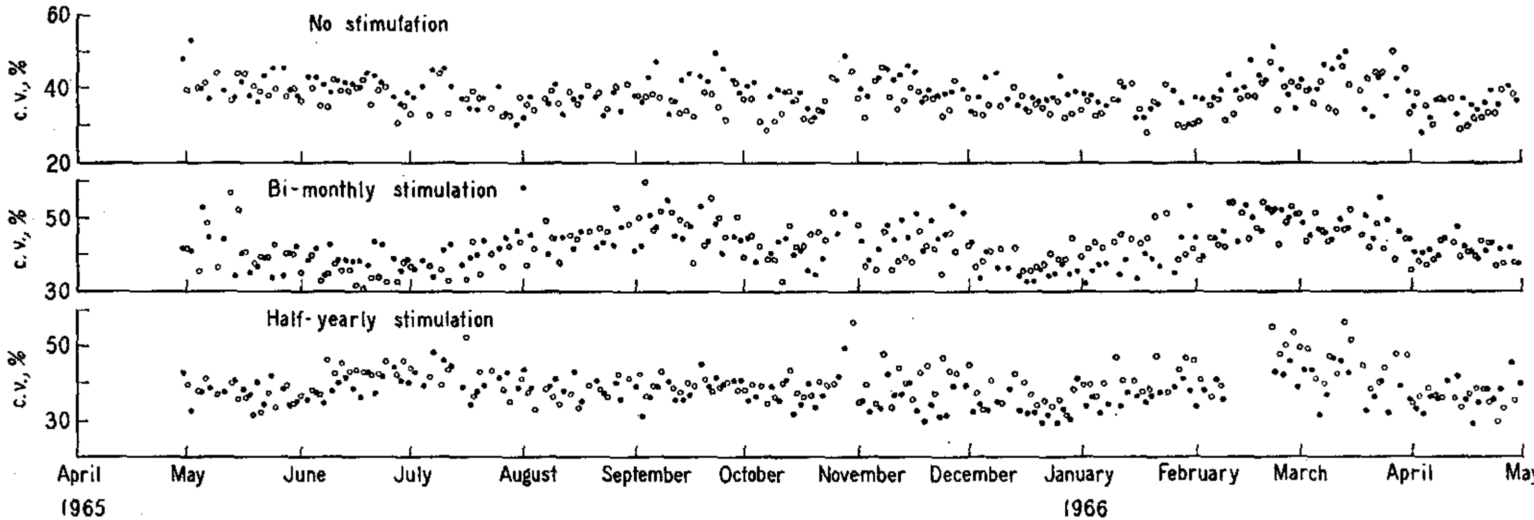

Figure 2. Coefficients of variation (c.v.) of daily yield records of 24 trees for the three treatments—Clone PR 107: S/2.d/2.100%.

TABLE 1. FREQUENCY DISTRIBUTIONS OF C.V.M. FOR DAILY YIELD RECORDS OF DIFFERENT CLONES

Clone	PR 107			PB 86			Clone	RRIM 605	
	Stimulation			Stimulation				Stimulation	
Class interval	Nil	Bi-monthly	Half-yearly	Nil	Bi-monthly	Half-yearly	Class interval	Nil	Half-yearly
3.50— 4.00	—	—	—	—	1	—	4.00— 5.00	—	1
4.00— 4.50	—	—	—	2	3	—	5.00— 6.00	3	16
4.50— 5.00	—	—	—	9	12	—	6.00— 7.00	38	38
5.00— 5.50	—	—	—	33	30	5	7.00— 8.00	81	70
5.50— 6.00	5	—	2	35	41	27	8.00— 9.00	77	63
6.00— 6.50	13	2	15	34	32	49	9.00—10.00	55	41
6.50— 7.00	41	15	32	25	26	34	10.00—11.00	27	40
7.00— 7.50	45	27	55	13	9	22	11.00—12.00	22	29
7.50— 8.00	74	45	62	4	3	15	12.00—13.00	8	11
8.00— 8.50	63	50	61	2	1	5	13.00—14.00	3	9
8.50— 9.00	37	53	41	2	—	1	14.00—15.00	2	—
9.00— 9.50	24	51	15	—	—	1	15.00—16.00	2	—
9.50—10.00	10	22	13	—	—	—	—	—	—
10.00—10.50	5	24	4	—	—	—	—	—	—
10.50—11.00	3	16	3	—	1	—	—	—	—
11.00—11.50	—	7	1	—	—	—	—	—	—
11.50—12.00	—	3	2	—	—	—	—	—	—
12.00—12.50	—	2	—	—	—	—	—	—	—
12.50—13.00	—	—	—	—	—	—	—	—	—
13.00—13.50	—	1	—	—	—	—	—	—	—
13.50—14.00	—	1	—	—	—	—	—	—	—
Total	320	319	306	159	159	159	Total	318	318

At $\alpha = 0.95$ in Equation (1), k becomes 2 and Equation (1) can be written as

$$P\ \{|\bar{x} - a| \leqslant\ 2(\text{c.v.m.})\bar{x}\}\ = 0.95 \quad \ldots(1a)$$

Thus the accuracy of $(\bar{x} - a)$ depends mainly on the observed coefficient of variation of the Mean.

Using the Equation (NARAYANAN, 1965)

$$n_2 = \frac{(\text{c.v.m.}_1)^2}{(\text{c.v.m.}_2)^2} \times n_1 \qquad \ldots(2)$$

the sample size n_2 required to achieve a desired coefficient of variation of the Mean (c.v.m.$_2$) can be calculated on the basis of the observed coefficient of variation of the Mean (c.v.m.$_1$) of the sample of size n_1.

The frequency distributions of the observed c.v.m.'s of the daily yield records have been used to calculate the likelihood of c.v.m.'s being less than any chosen value (*Figure 4*) and hence to determine the c.v.m. values corresponding with the 50%, 90% and 95% points (*Table 2*).

Putting the desired levels of c.v.m.'s as 5, 6, 7 and 8% in each of the cases, the minimum number of trees (or replicates) necessary for the accurate estimation of a daily treatment Mean has been worked out using Equation (2) and these are tabulated in *Table 3*, which shows that if the Mean on a 30-tree sample of PR 107 or RRIM 605 is taken, there is an even chance [$P(\text{c.v.m.} \leqslant d/2) = 0.5$, where d is the accuracy] that it will be within ±16% of the true Mean; if one wants to be 95% sure [$P(\text{c.v.m.} \leqslant d/2) = 0.95$], about 40 trees are necessary with PR 107 and a 60-tree sample with RRIM 605. There is an even chance of a 25-tree sample of PB 86 being within ±12% of the true Mean, a 90% chance of being within ±14% and a 95% chance of being within ±16%. The circumstances of an experiment—site, clone, panel tapped, etc—determine the number of replicates required for a given level

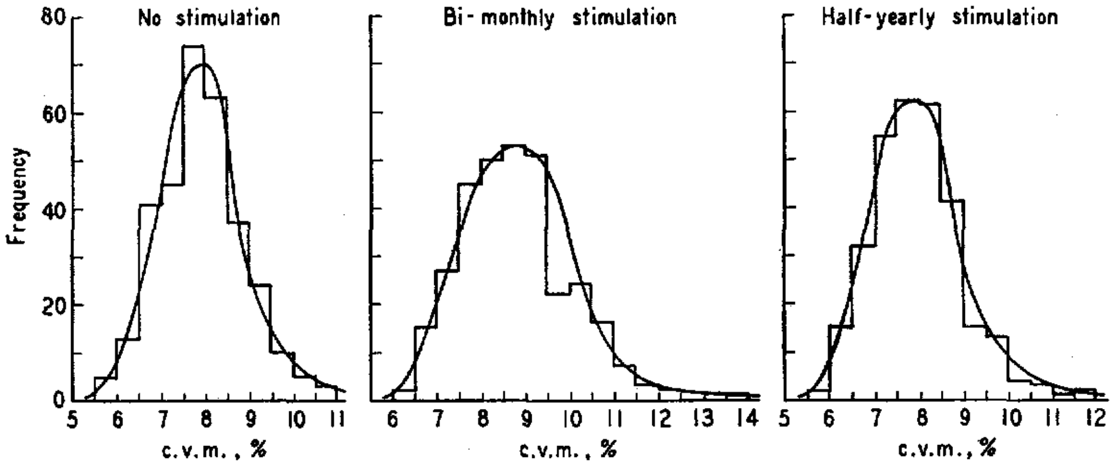

Figure 3. Frequency distributions of observed c.v.m.'s of daily yield records of 24 trees for the three treatments—Clone PR 107: S/2.d/2.100%.

of accuracy in the estimation of daily treatment Means. As the required accuracy of estimation of the daily Mean yield increases, the number of trees needing recording increases. At the 50% c.v.m. point, 50 trees would be needed to estimate the mean daily yield to within ±12% of the Mean (c.v.m. = 6%) with PR 107 and RRIM 605. Correspondingly more trees are needed for the 90% and 95% c.v.m. points (*Table 3*).

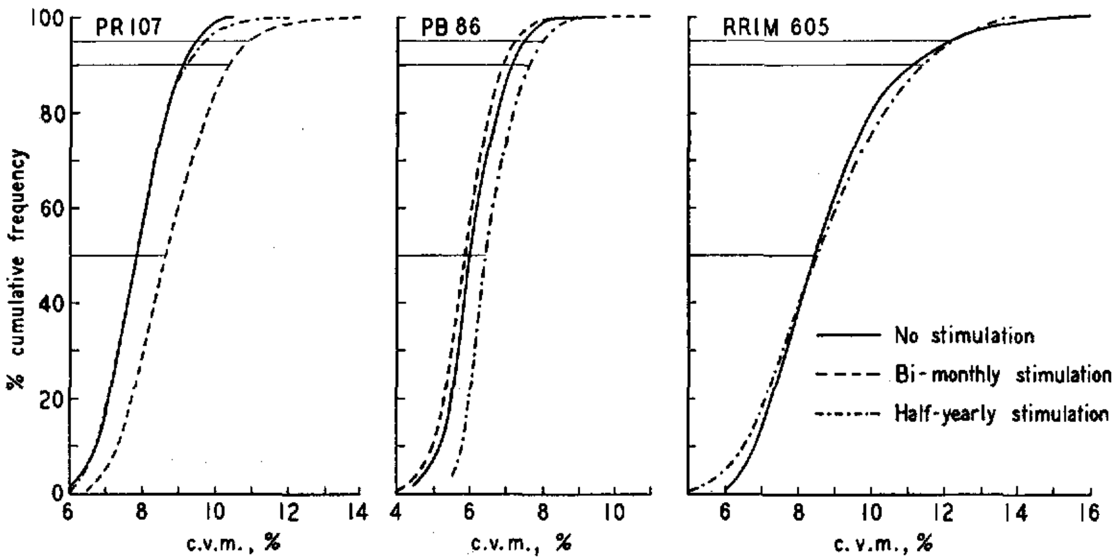

Figure 4. Percentage cumulative frequency distributions of observed c.v.m.'s of daily yield records of 24 trees for the different treatments of 3 clones: S/2.d/2.100%.

TABLE 2. PERCENTAGE POINTS* OF THE C.V. AND C.V.M. DISTRIBUTIONS

Clone	Treatment	c.v.			c.v.m.		
		50%	90%	95%	50%	90%	95%
PR 107	Stim. nil	38.5	44.8	46.8	7.85	9.15	9.55
	Stim. bi-monthly	42.6	50.7	53.6	8.70	10.35	10.95
	Stim. half-yearly	38.5	45.3	47.8	7.85	9.25	9.75
PB 86	Stim. nil	29.4	35.0	37.2	6.00	7.15	7.60
	Stim. bi-monthly	28.9	34.0	35.8	5.90	6.95	7.30
	Stim. half-monthly	31.8	37.5	39.2	6.50	7.65	8.00
RRIM 605	Stim. nil	41.4	54.4	59.3	8.45	11.10	12.10
	Stim. half-yearly	41.9	56.6	60.7	8.55	11.55	12.40

* These values have been read from the graphs of the percentage cumulative distributions. c.v.=c.v.m.$\times\sqrt{24}$

TABLE 3. NUMBER* OF TREES NECESSARY FOR ESTIMATING THE TRUE TREATMENT MEAN WITH CONFIDENCE LIMITS NOT GREATER THAN $\bar{x}\pm 2$(c.v.m.)$\bar{x}$

Clone	Treatment	50%	90%	95%	50%	90%	95%	50%	90%	95%	50%	90%	95%
		Desired levels of c.v.m. for daily yields											
		5%			6%			7%			8%		
PR 107	Stim. nil	59	80	88	41	56	61	30	41	45	23	31	34
	Stim. bi-monthly	73	103	115	50	71	80	37	52	59	28	40	45
	Stim. half-yearly	59	82	91	41	57	63	30	42	47	23	32	36
PB 86	Stim. nil	35	49	55	24	34	39	18	25	28	14	19	22
	Stim. bi-monthly	33	46	51	23	32	36	17	24	26	13	18	20
	Stim. half-yearly	41	56	61	28	39	43	21	29	31	16	22	24
RRIM 605	Stim. nil	69	118	141	48	82	98	35	60	72	27	46	55
	Stim. half-yearly	70	128	148	49	89	103	36	65	75	27	50	58

* For these numbers of trees, the 95% confidence interval for the true daily tapping treatment Mean will be no larger than $\bar{x}$ $\pm$2(c.v.m.)$\bar{x}$. The percentage points of the c.v.m. show the probability that the c.v.m.'s will not be exceeded in 50%, 90% and 95% of the cases. These percentage points have been reduced to the desired c.v.m. levels and hence the minimum number of trees has been obtained—see Equation (2). $\bar{x}$ is the new sample Mean based on these numbers and 'a' is the true treatment Mean.

Number of Replications to Establish Significant Difference between Two Tapping Treatments

The number of replications (n) that need to be provided in an experiment is determined by:

(a) Magnitude of the differences between any two treatments (expressed as a percentage of the Mean) required to detect;

(b) Inherent variability of the experimental material (expressed as the c.v. of a representative sample);

and (c) The number of treatments to be compared.

The relationship is given by

$$n \geqslant \frac{2s^2t^2}{d^2} \qquad \ldots(3)$$

where d is the observed difference that it is desired to detect,

s^2 is an estimate of the true variance, and

t is the appropriate Student's t-value at the desired significant level.

In the computation presented here, the situation with only two treatments (and Student's t-value for $2(n-1)$ degrees of freedom) is considered, though Equation (3) can be applied to any number of treatments. Using the c.v. value indicated as representative for each of the clones in *Table 2*, Equation (3) has been applied to the calculation of the number of replications (or trees) required for detecting differences of the order of 15% and of 20% of the Means (*Table 4*). These indicate clearly that there is an even chance of 40 replicates (or trees) of PR 107 and RRIM 605 being sufficient to detect tapping treatment differences of the order of 15% of the Mean. At the 90% c.v. point, only differences of the order of 20% of the Mean would be detected with that number of replicates of RRIM 605 (or with 30 replicates of PR 107).

Variations due to Trees and Days in a Month

To determine the extent to which the variation in daily yields is attributable to 'tree' and 'day' variations respectively, the total variation of the non-stimulated PR 107 S/2.d/2.100% data was analysed into 'tree variation', 'day variation' and 'trees × days interaction and random variation' for the different months. The analyses were done separately for each of the two groups of 24 trees and then combined.

Assuming the different sources of variation as random, the components of variance giving estimates of the true 'tree variation' (σ_1^2) and true 'day variation' (σ_2^2) are given in *Table 5*. The ratio of the two components of variance σ_1^2/σ_2^2 ranges between 5 and 50 in the different months, indicating 'day variation' to be small or negligible compared to 'tree variation' for the different months. Thus, the precision of a monthly treatment Mean of daily yield records can be increased more expeditiously by increasing the number of trees than by increasing the number of recording days in a month.

The standard error (s.e.) of a monthly treatment Mean based on t trees and d days is given by (BROWNLEE, 1960) as:

$$\text{s.e.}^2 = \frac{\sigma_1^2}{t} + \frac{\sigma_2^2}{d} + \frac{\sigma_0^2}{td}$$

where σ_1^2 and σ_2^2 are as already defined and

TABLE 4. NUMBER OF REPLICATES* NECESSARY FOR DETECTING SIGNIFICANT DIFFERENCES BETWEEN TWO TAPPING TREATMENTS

% Point	50%		90%		95%	
Size of d	15% of Mean	20% of Mean	15% of Mean	20% of Mean	15% of Mean	20% of Mean
Clone PR 107	40	23	50	28	61	35
Clone PB 86	23	13	30	18	30	18
Clone RRIM 605	40	23	73	42	87	50

* r is the number of replicates such that the difference between two tapping treatment Means of size d (expressed as a percentage of the common Mean) will be detected as significant at 10% level of significance (two-tailed). The assumption is that the populations are normal and have the same variance.

TABLE 5. COMPONENTS OF VARIANCE SHOWING ESTIMATES OF TRUE 'TREE' AND 'DAY' VARIATIONS
(Clone PR 107; S/2.d/2.100% without stimulation)

Month		Components of variance			$\frac{\sigma_1^2}{\sigma_2^2}$	Means (g)
		σ_0^2	σ_1^2	σ_2^2		
May	1965	96.78	426.27	66.21	6.44	54.9
June		69.26	644.52	12.93	49.85	67.1
July		107.22	504.40	11.56	43.63	66.7
August		104.88	621.56	70.96	8.76	72.3
September		105.98	719.42	77.86	9.24	71.5
October		101.05	542.55	27.48	19.74	68.4
November		111.04	623.34	34.14	18.26	68.0
December		82.36	581.29	45.12	12.88	70.2
January	1966	107.37	566.69	51.80	10.94	73.8
February		118.39	523.54	114.56	4.57	63.2
March		117.89	247.18	6.16	40.13	44.9
April		85.60	321.88	15.26	21.09	57.5

σ_0^2=Estimate of the true 'trees × days and random variation'.
σ_1^2=Estimate of the true 'tree variation'.
σ_2^2=Estimate of the true 'day variation'.

σ_0^2 is an estimate of the true 'trees × days interaction and random variation'.

Table 6 shows the s.e. and c.v. of a monthly treatment Mean on the basis of 50 trees and of 1, 2 and 3 recording days in a month for the different months. The reduction in the s.e. of a treatment Mean from increasing the number of recording days from two to three is much less than from increasing the number of recording days from one to two per month.

Distribution Pattern of Single Tree Yields

The pattern of the distribution of the individual tree yields for the 300 trees of clone PB 86 is shown in *Figure 5*; the distribution is somewhat skew to the right. Similar skewness in the distribution of single tree yields has been reported for cacao by CUNNINGHAM AND BURRIDGE (1959) and for Robusta coffee by BUTTERS (1964). Logarithmic and square-root transformation respectively and grouping of individual tree records into multiple tree groups were recommended for correcting skewness and making the distribution approach to normality. Calculation of the parameters g_1 and g_2 (FISHER, 1950) of departures from normality for various groupings of the daily yields of the 300 individual tree records shows a similar approach to normal distribution through grouping into multiple tree groups. Though the size of the sample reduces the precision of the estimates of g_1 and g_2 particularly for the larger tree groups, *Table 7* shows that these parameters are much reduced relative to their standard errors by grouping the tree records into pairs. Further reductions resulted from grouping into larger tree groups. On the basis of the limited data examined, grouping of eight trees and above would make the distribution of daily yields approach normality.

DISCUSSION

The preceding computations have established the desirability of grouping single trees for purposes of statistical analysis. Even in tapping experiments where border effects are of little consequence, it is convenient to group trees on a contiguity basis. No information is yet available on the relative merits of contiguous and scattered groupings for rubber but, for coconuts, a grouping of contiguous trees in association with a covariance analysis on appropriate pre-treatment measurements has been found to be quite effective (SHRIKHANDE, 1957) for

TABLE 6. STANDARD ERROR AND C.V. OF A MONTHLY TREATMENT MEAN USING 50 TREES AND 1, 2 AND 3 RECORDINGS IN A MONTH
(Clone PR 107; S/2.d/2.100% without stimulation)

Month		s.e. of a treatment Mean			c.v. of a treatment Mean		
		Using 50 trees/day and number of recording days taken as			Using 50 trees/day and number of recording days taken as		
		once a month	twice a month	thrice a month	once a month	twice a month	thrice a month
May	1965	8.76	6.53	5.59	15.96	11.89	10.18
June	"	5.22	4.48	4.21	7.78	6.68	6.27
July	"	4.88	4.12	3.83	7.32	6.18	5.74
August	"	9.25	7.00	6.06	12.79	9.68	8.38
September	"	9.71	7.37	6.41	13.58	10.31	8.97
October	"	6.35	5.06	4.55	9.28	7.40	6.65
November	"	6.99	5.54	4.96	10.28	8.15	7.29
December	"	7.64	5.92	5.22	10.88	8.43	7.44
January	1966	8.08	6.16	5.41	10.95	8.35	7.33
February	"	11.29	8.30	7.03	17.86	13.13	11.12
March	"	3.67	3.03	2.79	8.17	6.75	6.21
April	"	4.84	3.86	3.48	8.42	6.71	6.05

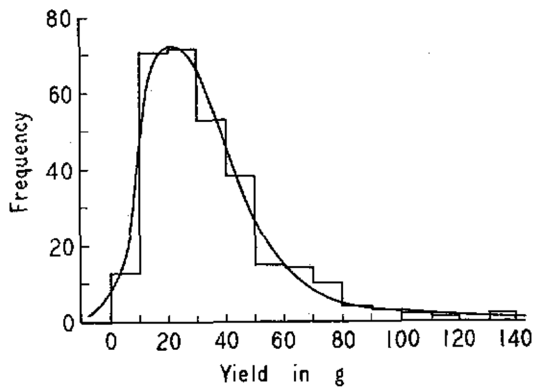

Figure 5. Frequency distribution of daily yield records of about 300 trees for clone PB 86 (Date of coagulation:28.12.'54).

removing pre-treatment differences as allocation of treatments on the basis of such measurements. Covariance analysis of yield records has been found helpful (NARAYANAN, 1966) in reducing the experimental error in *Hevea* at least in the initial three years when pre-treatment yield records are considered. The proposal to employ double covariance (PEARCE AND BROWN, 1960) on both the pre-treatment girth and yield records needs examination.

The study indicates that the coefficient of variation (c.v.) of the daily yield records of single trees does not show any pattern with the different seasons or with stimulation. There is indication that the c.v. of the daily yields is determined by the circumstances—site, clone, panel tapped, etc.—of the experiment. Based on the different percentage points of the c.v.m. distributions, the minimum number of trees necessary for accurate estimation of a tapping treatment Mean as well as for distinguishing treatment differences has been found to be 50 (*Tables 3* and *4*). It would be preferable to have grouping of eight or more trees as a unit or plot (random or contiguous) rather than a single tree as a unit, since the distribution of yields of single trees is somewhat skew. The 50 trees per treatment could be conveniently split up as five or six replicates of ten or eight trees per plot for each replicate. Variation 'between trees' is more pronounced than variation 'between days' in a month and for the estimation of a monthly treatment Mean, the number of recordings can be confined to one or two

TABLE 7. VALUES OF g_1 AND g_2 STATISTICS AND THEIR STANDARD ERRORS FOR DIFFERENT GROUPINGS OF TREES
(Data of daily yields of clone PB 86 for a task of about 300 trees recorded on 28.12.'54)

	Grouping of trees of							
	1	2	3	4	5	6	8	10
n	298	149	99	74	59	49	37	29
Mean	34.23	34.07	33.91	33.72	34.03	33.83	33.75	34.01
S.d.	21.87	15.61	13.35	11.91	10.67	10.39	8.86	8.56
g_1	1.560	1.105	1.258	1.176	1.024	1.091	0.554	0.452
g_2	3.304	1.216	1.596	1.840	1.052	1.415	−0.122	−0.578
S.e. of $g_1(\sigma g_1)$	0.141	0.199	0.242	0.279	0.311	0.340	0.388	0.434
S.e. of $g_2(\sigma g_2)$	0.281	0.395	0.481	0.552	0.613	0.668	0.759	0.845
$g_1/\sigma g_1$	11.14	5.55	5.20	4.21	3.29	3.21	1.43	1.04
$g_2/\sigma g_2$	11.80	3.08	3.32	3.33	1.72	2.12	−0.16	−0.68

$g_1=\frac{\mu_3}{\mu_2{}^{3/2}}$, $g_2=\frac{\mu_4}{\mu_2{}^2}-3$ where the μ's are the central moments of the sample distribution of yields.

days in a month. Since the mean daily yield for the different months shows large seasonal effects, statistical analysis of the yield data for these experiments should be done on an annual basis using at least two recorded tappings each month for each of the treatments.

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