J. nat. Rubb. Res. **10(2)**, 124–142

Some Aspects of Statistical Application in Rubber Breeding Trials#

H. TAN*

Rubber breeding trials are usually long-term and costly due to the perennial nature of the tree. Thus the experimental economy and precision in rubber breeding trials are important. This paper reviews various aspects of rubber breeding experimental designs applied in two types of trials; small-scale clone trials (SSCT) and large-scale clone trials (LSCT) at the RRIM.

In SSCT, 6 trials were examined in relation to yield and girth performance using simple lattice design. Average values of trial CV were 8.4% to 26.3% with the highest value for yield per tree (26.3%) followed by girth increment (24.0%) and girth (8.4% – 10.9%). Relative efficiency for simple lattice design over randomised block design ranges from 2.4% to 11.3%.

In LSCT, randomised block design as well as more sophisticated designs (such as simple lattice, balanced lattice and incomplete block designs) over randomised block design were also generally low. About 27% of the total cases studied showed more than 20% gain in precision.

The findings of 9% – 27% of the total cases studied so far having achieved more than 20% gain in efficiency with the more sophisticated experimental designs over the randomised block design in rubber breeding trials merits consideration for the use of sophisticated designs.

The para rubber, *Hevea brasiliensis*, is a perennial tree crop. It has a long generative and testing cycle. Normally, it takes about four to five years for one generative cycle (exluding seven to ten years of evaluation period for parental performance) and about 20 to 30 years for one testing cycle from the time of cross-pollination[1]. Because of the nature of this crop, breeding trials are long-term and costly. Trials usually need long-term commitment of large experimental areas and considerable human resources. Thus, rubber breeders are very concerned with experimental economy and precision in their trials.

In the Rubber Research Institute of Malaysia (RRIM), breeding programmes started in 1928. Since then, a large number of progenies have been produced annually from the hand pollination programme carried out by the Institute (with short interruption during the war and economic depression periods). Conventionally, the progenies obtained were cloned and tested in small-scale clone trials (with or without early selection in field nursery) followed by large-scale clone trials. However, in recent years, this conventional approach is complemented by an accelerated approach which involves testing the elite progenies

#Paper presented at the 1981 International Society for Oil Palm Breeders International Workshop on 'Applications of Statistics to Perennial Tree Crops', Kuala Lumpur

*Rubber Research Institute of Malaysia, P.O. Box 10150, 50908 Kuala Lumpur, Malaysia

results with reference to experimental design and its precision relative to randomised blocks in seven SSCT. They reported that the improvement of trial precision in using simple lattice design relative to randomised blocks was low or insignifficant in most cases studied.

Tan[24] extended a similar study using data from SSCT and his findings are desribed below. *Table 1* shows trial coefficient of variation (CV) and relative efficiency (RE) in four SSCT testing 256 to 625 genotypes in simple lattice design. Mean yield over five years had the highest CV (26.3%) followed by girth increment (23.9%) and girth (9.7%).

As for the RE of the simple lattice design over the randomised block design, girth at fourth year was the highest (118.3%) followed by girth increment on tapping (111.3%), girth at opening (109.4%), and girth after five years tapping (104.4%), A mean RE of 108.1% with a range of between 100.3% and 141.8% was obtained when all the characters are considered jointly.

The results obtained in this study were similar to those of Narayanan et al[21]. Trial CV values obtained for yield and girth characters were considered acceptable, reflecting reasonable trial reliability. Although the RE values in using simple lattice over randomised blocks were low in magnitude, positive improvement in trial precision for several cases studied was detected. In certain cases, the gain in trial precision was substantial *e.g.* 26.8% and 41.8%. It is therefore useful to adopt the simple lattice design for testing a large number of genotypes in SSCT.

TABLE 1. TRIAL CV (%) AND RE (%) OF YIELD AND GIRTH PERFORMANCE IN FOUR SMALL-SCALE CLONE TRIALS WITH SIMPLE LATTICE DESIGN

Character	Statistical parameter	Expt.1	Expt.2	Expt.3	Expt.4	Overall mean
Mean yield/tree	CV	27.8	24.8	25.6	26.8	26.3
	RE	100.3	104.9	100.9	103.6	102.4
Girth at 4th year	CV	12.2	9.0	13.9	8.6	10.9
	RE	141.8	115.1	104.7	111.4	118.3
Girth at opening	CV	11.3	7.6	7.2	7.4	8.4
	RE	126.8	109.6	100.2	103.3	109.4
Girth after 5 years tapping	CV	11.4	8.4	9.2	–	9.7
	RE	106.6	106.0	100.6	–	104.4
Immature girth increment	CV	22.4	13.2	45.8	13.7	23.8
	RE	101.3	106.2	100.0	104.6	103.0
Girth increment on tapping	CV	25.4	18.5	28.2	–	24.0
	RE	110.1	112.5	108.4	–	111.3

CV = Coefficient of variation in %
RE = Relative efficiency of design over randomised block in %
Yield was based on average of five years of tapping

COPYRIGHT © MALAYSIAN RUBBER BOARD

(based on early selection in field nursery) directly in large-scale clone trials (designated as promotion plot clone trials), bypassing the small-scale testing stage.

In the course of developing new cultivars, various statistical methods including experimental designs have been considered. Like other crop research, rubber breeding trials were conducted with the best knowledge available then with regard to the crop concerned, statistical information known and practical considerations. Usually, early trials were relied on limited statistical information and many of them were based on general principles and knownledge from other crops and with certain logical assumptions. As new infor- mation becomes available from earlier trials in the crop concerned, later trials are modified accordingly. In rubber breeding trials, various field designs, ranging from randomised blocks to incomplete blocks (balanced or unbalanced), and statistical methods have been attempted with the hope of improving trial precision and economy. Todate, large amounts of data have been generated from these trials. This source of data could be used for studies on the validity of early statistical assumptions and for evaluation of suitable trial designs including plot size, shape, block shape and number of replications and sites so as to serve as suitable guides for conducting future rubber breeding trials.

In rubber, discussions on statiscal problems in field experimentation can be found in Maas[2], Bishop *et al.*[3], Tengwall *et al.*[4], Barclay and Grantham[5], Murray[6], Posthumus *et al.*[7], Page[8], Westgarth[9] and Narayanan[10-12]. Some attention was given to studies on field designs including plot size and shape, block shape, number of replication and sites in rubber breeding trials (Westgarth[13], Paardekooper[14-17], Narayanan[18-19], Narayanan *et al.*[20-21], Iyer[22], Rossetti and Pimentel Gomes[23]. More recently, Tan[24] examined large yield and girth data sets collected over the years regarding trial precision in various breeding trials at the RRIM (*Appendix I*).

The main aim of this paper is to review some aspects of breeding trial designs including trial coefficient of variation, relative efficiency, plot size, plot shape, block shape, number of replications and sites based on previous work reported locally. It is hoped that this review could provide useful guide for conducting future breeding trials and stimulate more thinking on the status of modern statistical designs and techniques to improve breeding trial precision and economy.

SMALL-SCALE CLONE TRIALS (SSCT)

In the early years, all the seedling genotypes produced from breeding programmes were tested in field trials in randomised block design for yield and secondary characters. Later, as the number of genotypes increased due to the expansion of breeding programmes, only a smaller proportion of genotypes, which were preselected either based on early vigour or, more recently, on early test-tapping yield, were cloned and evaluated in SSCT using simple lattice design with the hope of improving experimental precision. The plot size used was six to twelve trees in a single row plot. This plot size was considered acceptable on the basis of the experimental objective which was for early screening of large number of genotypes with a wide range of genetic variability. Single row plot was considered for ease of recording and observation on secondary characters. Though not statistically proven as the most precise and ideal, the plot size and shape used were regarded as practical and effective in selecting superior genotypes in SSCT.

Ross[25] reported some results of early SSCT. Narayanan *et al.*[21] studied the experimental

TABLE 2. TRIAL CV (%) OF YIELD AND GIRTH PERFORMANCE IN EIGHT LARGE-SCALE CLONE TRIALS WITH RANDOMISED BLOCK DESIGN

Statistical parameter	Yield/tree	Yield/ha	Girth at opening	Girth increment on tapping
Mean	10.4	12.7	5.0	11.1
Standard deviation	2.16	2.26	2.30	2.59
Minimum	7.1	9.9	2.5	7.5
Maximum	13.8	16.2	8.9	14.5
No. of trials	8	8	8	8

Yield was based on five years of tapping
Source: Tan[24]

TABLE 3. TRIAL CV (%) OF YIELD AND GIRTH PERFORMANCE IN FIVE LARGE-SCALE CLONE TRIALS WITH SIMPLE LATTICE DESIGN

Character	Statistical parameter	Expt.1	Expt.2	Expt.3	Expt.4	Expt.5	Overall mean
Yield/tree	CV	9.1(28)	15.3(28)	12.6(28)	11.4(28)	13.5(7)	12.4(5)
	RE	113.3(28)	105.7(28)	109.7(28)	111.7(28)	103.5(7)	108.4(5)
Yield/ha	CV	11.7(28)	19.0(24)	18.0(28)	15.2(28)	19.2(7)	16.6(5)
	RE	110.4(28)	120.4(24)	114.1(28)	115.9(28)	106.7(7)	113.5(5)
Girth at 2nd year	CV	3.2(4)	4.2(4)	3.4(4)	6.0(4)	4.3(1)	4.2(5)
	RE	106.7(4)	106.8(4)	140.0(4)	110.5(4)	147.6(1)	122.3(5)
Girth at 4th year	CV	3.3(4)	3.7(4)	4.9(4)	–	3.5(1)	3.9(5)
	RE	117.9(4)	105.6(4)	125.2(4)	–	137.9(1)	121.7(5)
Immature girth increment	CV	4.8(4)	6.7(4)	4.0(4)	–	3.3(1)	4.7(5)
	RE	128.5(4)	110.7(4)	126.0(4)	–	106.6(1)	118.0(5)
Girth increment on tapping	CV	7.7(4)	11.1(4)	9.2(4)	11.2(4)	9.3(1)	9.7(5)
	RE	103.0(4)	100.6(4)	110.0(4)	130.5(4)	117.7(1)	112.4(5)

CV = Coefficient of variation in %
RE = Relative efficiency of design relative to randomised block design in %
Figures in parenthesis refer to sets of data analysed
Yield was based on variable periods of the first five years of tapping
Source: Tan[24]

LARGE-SCALE CLONE TRIALS (LSCT)

This is a more advanced stage of clonal testing. After evaluation of clonal performance in terms of yield and other secondary characteristics in SSCT a few promising genotypes which were superior to the control clones were selected and tested in LSCT in different environments (in Peninsular Malaysia) for their adaptability. As these trials are meant to test only a few selected promising clones, the plot size used is bigger and is usually square or rectangular in shape. Usually, one guard row is included in the plot to avoid border effects. Experimental designs used for the trials, depending on land availability and number of genotypes to be tested, include randomised blocks for a small set of genotypes, simple lattice for large number of genotypes, and balanced lattice and incomplete block designs when appropriate. Detailed information and results on some early LSCT were reported by Paardekooper[26-30] and Sultan[31]

Tan[24] studied the trial CV and RE for the different experimental designs used in the LSCT. The results are highlighted below.

Randomised Block Design

This design was generally adopted to test relatively a small number of clones. The number of clones (genotypes) involved in the eight trials studied ranged from six to ten with a plot size ranging from 75 to 125 trees, covering an area of between 0.14 ha to 0.28 ha. The experiments were each replicated four times.

Trial CV averaged 12.7%, 11.1%, 10.4% and 5.0% for yield/ha, girth increment on tapping, yield/tree and girth at opening, respectively (*Table 2*). These CV values are relatively small (below 13%), indicating the reliability and suitability of the randomised block design with four replications for LSCT with a small set of genotypes.

Simple Lattice Design

This design was used to test a large number of genotypes in LSCT. Five trials which tested 100 genotypes in a simple lattice design with two replications were studied. Plot sizes were 60 to 72 trees covering an area of between 0.15 ha to 0.20 ha/plot.

Averaging over all sites, trial CV were 12.4% and 16.6% for yield/tree and yield/ha, respectively (*Table 3*). CV values for immature girths ranged from 3.9% to 4.3% and values for girth increment ranged from 4.7% during immaturity to 9.7% on tapping. These low trial CV values indicate that the experiments conducted were reasonably reliable. Mean RE values for yield/tree and yield/ha were 108.4% and 113.5%, respectively. For girth data, mean RE values were about 121% for immature girths, 118% for girth increment during immaturity and 112% for girth increment on tapping.

It is interesting to note that the mean RE obtained for girth was slightly higher than that for yield, suggesting that girth would be a better parameter for the study of relative trial precision. Also, the relative improvement of trial precision in using simple lattice over randomised block designs was positive, although the gain was small in most experiments. Only about 29% of the cases studied showed more than 20% improvement in trial precision. This finding supports the contention of Narayanan *et al.*[21] that simple lattice design was useful in testing a large number of genotypes in LSCT.

Balanced Lattice Design

This design was used when the number of genotypes to be tested could form a perfect square with block size equal to the square root of the number of treatments and number of

TABLE 4. TRIAL CV (%) AND RE (%) FOR YIELD PERFORMANCE IN LSCT WITH 4 x 4 BALANCED LATTICED DESIGN

Experiment	Statistical parameter	Yield/tree	Yield/ha
1	CV	12.0	15.0
	RE	105.0	107.8
	N	13	13
2	CV	8.4	11.5
	RE	118.5	108.7
	N	10	10
3	CV	10.3	15.5
	RE	102.3	107.4
	N	9	9
4	CV	14.1	27.6
	RE	108.5	104.3
	N	10	10
5	CV	8.2	10.5
	RE	136.0	136.5
	N	10	10
6	CV	6.4	8.6
	RE	126.9	114.2
	N	10	10
7	CV	5.7	8.9
	RE	119.6	114.1
	N	4	4
Overall Mean	CV	9.3	13.9
	RE	116.7	113.3
	N	7	7

CV = Coefficient of variation in %
RE = Efficiency of design relative to randomised block design in %
N = No. of data sets used
Yield was based on up to 11 years of tapping
Source: Tan[24]

replications one more than the block size. The present deliberation included yield studies (11 years of tapping) on seven trials, while another six trials were used for girth performance studies (girth and girth increment during immaturity) with one of the trials common in both. The average plot size used was 64 trees with a range of 50 – 72 trees in an area of between 0.14 ha to 0.17 ha/plot. Planting density ranged from 373 – 450 trees/ha.

Mean CV for yield/tree was 9.3% with a range of 5.7% to 14.1% while that for yield/ha was 13.9%, ranging from 8.6% to 27.6% (*Table 4*). Mean CV for girths (2nd – 4th year) during immaturity was 4.7% with a range of between 3.2% and 7.0% (*Table 5*). Girth at opening gave a trial CV of 3.3% (range: 2.6% – 4.2%). Mean CV for girth increment during immaturity was 5.6% (range: 4.4% – 6.7%). The relative magnitudes in mean CV for the characters studied were yield/ha (13.9%), yield/tree (9.3%), immature girth increment (5.6%), immature girth (4.7%) and girth at opening (3.3%) in descending order. Trial mean CV values for yield and girth characters were low, reinforcing the confidence in the experimental results.

Mean RE for yield/tree in the trials studied was 116.7% (range: 102.3% – 136.0%) while that for yield/ha was 113.3% (range: 104.3% – 136.5%). Mean RE values for immature girth, girth at opening and immature girth increment were 115.0% (range: 104% – 130.6%), 106.1% (range: 100.0% – 121.2%) and 114.9% (range: 106.1% – 127.4%), respectively. The relative magnitudes in mean RE for the characters studied were yield/tree (116.7%), immature girth (115.0%), immature girth increment (114.9%), and yield/ha (113.3%) and girth at opening (106.1%) in descending order. Average gains in efficiency in using the balanced lattice design over the randomised blocks varied from 6.1% in girth at opening to 16.7% in yield/tree.

When individual experiments and characters were considered together, 45.2%, 61.3% and 74.2% of the cases studied showed corresponding gains in precision by less than 10%, 15% and 20% respectively, over the randomised block design. It also follows that only about 25.8% of the cases studied gave a gain in trial precision by over 20%. This extra gain in precision in some cases justifies the use of the above design in large-scale testing in rubber breeding trials.

Balanced Incomplete Block Design

This design belongs to one of the groups in incomplete block designs in which the analyses and layout are well described in Cochran and Cox[32]. Nine trials in balanced incomplete block design are studied. Three of the trials tested 21 clones in five replications while the other six trials tested 13 clones in four replications. The plot size for these trials ranged from 34 – 90 trees per plot (0.09 ha – 0.20 ha). Planting density for these trials averaged 494 trees/ha (range: 399 – 598 trees/ha). The characters involved in the study were yield/tree, yield/ha (over five years of tapping), girth at opening and girth increment on tapping (four to five years).

Trial CV values (*Table 6*) averaging over the trials studied were 20.2% (range: 3.4% – 7.2%) for yield/ha, yield/tree, girth increment on tapping and girth at opening respectively. The CV values fall within the normal expection in most of our trials, thus suggesting that the trials are reliable.

Mean RE for yield/tree was 119.9% (range: 105.4% – 151.4%) while that for yield/ha was 112.3% (range: 100.4% – 134.9%). Mean RE values for girth at opening and girth increment were 128.4% (range: 100.1% – 221.7%) and 119.4% (range: 100.0% – 204.0%), respectively. The improvement in precision as judged

TABLE 6. TRIAL CV (%) AND RE (%) OF YIELD AND GIRTH PERFORMANCE IN NINE LSCT WITH BALANCED INCOMPLETE BLOCK DESIGN

Experiment	Statistical parameter	Yield/ tree	Yield/ ha	Girth at opening	Girth increment on tapping
1	CV	14.3	19.0	3.6	9.6
	RE	119.5	134.9	221.7	204.0
	N	6	6	1	1
2	CV	11.7	15.4	5.6	14.2
	RE	111.5	100.4	100.1	100.6
	N	6	6	1	1
3	CV	14.7	22.9	6.1	14.2
	RE	105.4	112.3	102.1	152.1
	N	6	6	1	1
4	CV	15.7	18.0	3.4	10.9
	RE	136.4	114.4	109.2	104.3
	N	6	6	1	1
5	CV	13.3	20.2	–	9.9
	RE	108.9	101.8	–	100.0
	N	6	6	–	1
6	CV	13.7	18.2	3.4	15.1
	RE	109.8	105.2	102.0	100.0
	N	6	6	1	1
7	CV	13.0	21.4	–	9.2
	RE	112.8	104.4	–	100.0
	N	6	6	–	1
8	CV	12.0	19.2	3.4	12.8
	RE	123.5	105.4	113.0	100.0
	N	5	5	1	1
9	CV	14.8	27.6	7.2	13.4
	RE	151.4	121.9	150.9	112.0
	N	5	5	1	1
Overall mean	CV	13.7	20.2	4.7	12.1
	RE	119.9	111.2	128.4	119.4
	N	9	9	7	9

CV = Coefficient of variation in %
RE = Efficiency of design relative to randomised block design in %
N = No. of data sets used
Yield was based on five years of tapping
Source: Tan[24]

TABLE 5. TRIAL CV (%) AND RE (%) FOR GIRTH PERFORMANE IN SIX LSCT WITH 4 × 4 BALANCED LATTICE DESIGN

Experiment	Statistical parameter	Immature girth	Girth at opening	Immature girth increment
1	CV	4.2	3.0	5.0
	RE	105.6	100.0	109.0
	N	3	1	3
8	CV	4.6	2.6	4.4
	RE	130.6	101.9	127.4
	N	3	1	3
9	CV	3.5	2.6	5.5
	RE	104.2	101.3	115.6
	N	3	1	3
10	CV	3.2	–	5.2
	RE	112.4	–	117.0
	N	3	–	2
11	CV	7.0	4.0	6.6
	RE	111.5	106.1	106.1
	N	3	1	3
12	CV	5.8	4.2	6.7
	RE	125.7	121.2	114.1
	N	3	1	3
Overall mean	CV	4.7	3.3	5.6
	RE	115.0	106.1	114.9
	N	6	5	6

CV = Coefficient of variation in %
RE = Efficiency of design relative to randomised block design in %
N = No. of data sets used
Immature girth was based on 2nd to 4th year girth measurements
Source: Tan[24]

TABLE 7. COMPARISON OF MEAN CV (%) OF BREEDING TRIALS WITH DIFFERENT EXPERIMENTAL DESIGN

Character		SSCT simple lattice	LSCT randomised block	LSCT simple lattice	LSCT balanced lattice	LSCT balanced incomplete block	LSCT overall mean
Yield/tree	a)	26.3 ± 1.3	10.4 ± 2.2	12.4 ± 2.3	9.3 ± 3.0	13.7 ± 1.3	11.5 ± 2.0
	b)	24.8 – 27.8	7.1 – 13.8	9.1 – 15.3	5.7 – 14.1	11.7 – 15.7	9.3 – 13.7
	c)	4	8	5	7	9	4
Yield/ha	a)	-	12.7 ± 2.3	16.6 ± 3.2	13.9 ± 6.6	20.2 ± 3.5	15.9 ± 3.3
	b)	-	9.9 – 16.2	11.7 – 19.2	8.6 – 27.6	15.4 – 27.6	12.7 – 20.2
	c)	-	8	5	7	9	4
Immature girth	a)	10.9 ± 2.6	-	4.1 ± 0.9	4.7 ± 1.5	-	4.4 ± 0.4
	b)	8.6 – 12.2	-	3.2 – 6.0	3.2 - 7.0	-	4.1 – 4.7
	c)	4	-	9	6	-	2
Mature girth	a)	8.9 ± 1.8	5.0 ± 2.3	-	3.3 ± 0.8	4.7 ± 1.6	4.3 ± 0.9
	b)	7.2 – 11.4	2.5 – 8.9	-	2.6 – 4.2	3.4 – 7.2	3.3 – 5.0
	c)	7	8	-	5	7	3
Immature girth increment	a)	23.8 ± 15.3	-	4.7 ± 1.5	5.6 ± 0.9	-	5.2 ± 0.6
	b)	13.2 – 45.8	-	3.3 – 6.7	4.4 – 6.7	-	4.7 – 5.6
	c)	4	-	4	6	-	2
Girth increment on tapping	a)	24.0 ± 5.0	11.1 ± 2.6	9.7 ± 1.5	-	12.1 ± 2.3	11.0 ± 1.2
	b)	18.5 – 28.2	7.5 – 14.5	7.7 – 11.2	-	9.2 – 15.1	9.7 – 12.1
	c)	3	8	5	-	9	3

a = Mean and standard deviation
b = Range including minimum and maximum values
c = No. of data sets involved in estimation
Source: Tan[24]

from all the analyses (including individual experiments and different characters) varied from 0% to 121.7%. Only 26.5% of the cases studied, however, showed more than 20% gain in precision in using balanced incomplete block design relative to randomised block design. About 52.9%, 70.6% and 73.5% of the total cases studied showed less than 10%, 15% and 20% gain, respectively in trial precision to relative randomised block design. These results are fairly similar to those found in trials using other experimental designs.

Comparisons of CV and RE in Trials with Different Designs

Table 7 summarises the mean trial CV values obtained from various breeding trials (small-scale and large-scale) with respect to yield and girth characters studied. In general, the mean CV values obtained in SSCT were relatively higher than those obtained in LSCT for the same character studied. The relative order in CV magnitude for the various character, however, was broadly similar in both the SSCT and LSCT. Yield gave the higher trial CV values followed by girth increments and then girths. In SSCT, trial CV values were 26.3% for yield, 23.8% – 24.0% for girth increments and 8.9% – 10.9% for girth. In LSCT, averaging over the various designs used, trial CV values were 11.5% – 15.9% for yield, 5.2% – 11.0% for girth increments and 4.3% – 4.4% for girths.

The difference in trial CV values for the SSCT and LSCT could be attributed to the smaller plot size and number of replications used in the former. A higher degree of trial reliability, as reflected by lower trial CV, could be expected for LSCT.

Table 8 summarises the mean RE values obtained in SSCT and LSCT in using various experimental designs over the randomised block design. Mean RE values for SSCT were generally lower than those for LSCT with reference to yield and girth characters. For yield, mean RE in SSCT was 102.4% (range: 100.3% – 104.9%) compared with 115.0% (range: 108.4% – 119.9%) in LSCT in the case of yield/tree and 113.0% (range: 111.2% – 113.5%) in the case of yield/ha. For girths, mean RE in SSCT was 118.3% (range: 104.7% – 141.8%) compared with 118.5% (range: 115.0% – 122.0%) in LSCT for girth during immaturity; a mean RE of 107.6% (range: 100.2% – 126.8%) in SSCT compared with 117.3% (range: 106.1% – 128.4%) in LSCT for girth at maturity. For girth increments, mean RE in SSCT was 103.0% (range: 100.0% – 106.2%) compared with 116.5% (range: 114.9% – 118.0%) in LSCT during immaturity; while mean RE for girth increment during maturity was 111.3% (range: 108.4% – 112.5%) in SSCT and 115.9% (range: 112.4% – 110.4%) in LSCT. In general, there appears to have a tendency of slightly higher mean RE for girth compared to that of yield character. This may suggest that girth may be preferred to yield for evaluating trial efficiency of various experimental designs.

Table 9 compares the distribution of mean RE in selected cumulative class intervals obtained from various designs in the breeding trials studied. In general, the gain in precision in SSCT was less than those in LSCT. Only about 9.1% of the total cases studied in SSCT showed more than 20% gain in precision as compared to about 27% of the cases studied in LSCT. In LSCT, the pattern of cumulative distribution for mean RE appears to be fairly similar in the three designs studied. The percentage of the cases falling within the categories of less than 5%, 10%, 15% and 20% gain in precision were 21.5% (range: 10.7% – 32.4%), 46.2% (range: 39.3% – 52.9%), 64.5% (range:60.7% – 70.6%) and 73.1% (range: 71.4% – 74.2%), respectively. The higher trial precision in LSCT as compared to SSCT is not surprising (as reflected by relative trial CV

TABLE 9. PERCENTAGE OF TOTAL CASES FALLING IN VARIOUS CLASS INTERVALS OF TRIAL PRECISION GAIN IN BREEDING TRIALS STUDIED

Percentage precision gain	SSCT simple lattice (22)	LSCT simple lattice (28)	LSCT balanced lattice (31)	LSCT balanced Incomplete blocks (34)	LSCToverall mean (93)
0 - 5	50.0	10.7	19.4	32.4	21.5
0 - 10	72.7	39.3	45.2	52.9	46.2
0 - 15	90.9	60.7	61.3	70.6	64.5
0 - 20	90.9	71.4	74.2	73.5	73.1
> 20	9.1	28.6	25.8	26.5	26.9

Figures in parenthesis refer to total number of cases analysed
Source: Tan[24]

described earlier), considering the larger plot size and number of replications used.

Other Aspects of Trial Design

Convenient plot size, shape, block shape, number of replications and sites are pertinent questions associated with experimental design and efficiency in trials. These matters are not only addressed to the theoretical consideration but also to financial, practical and other considerations[13,33,17]

In rubber only a few workers have dealt with topics related to plot size, shape, block shape, number of replications and sites. Some important studies related to LSCT are reviewed below.

Plot Size

Westgarth[13] started discussion on the issue of optimum plot size in LSCT for rubber. Using certain assumptions on the CV of characters, he derived a relationship on number of recorded trees/plot, number of plots/clone and corresponding variances. He inferred that the use of 25 recordings of trees in a plot size of 49 trees was acceptable. Paadekooper[14] discussed optimum plot size following Smith[34] and presented a curve showing the relationship between coefficient of soil heterogeneity, *b*, and the optimum number of recording points. He suggested that plot with 36 recording trees was acceptable as 'optimum plot size' provided *b* lies between 0.5 – 0.8. Later, coefficient of heterogeneity was estimated by Paardekooper[15-17] using girth from uniformity trials and LSCT. Coefficient of soil heterogeneity ranging from 0.20 to 0.67 were obtained. According to Paadekooper[17], the 'optimum plot size' for 'singly guarded row' (one boundary row) required 20–42 recording trees while that for 'doubly guarded row' (two boundary rows) of between 32 – 60 recording trees would be required. A recording tree number of between 20 – 72 trees would be required to allow loss in efficiency of up to 20%. Paardekooper[17] pointed out that other considerations influence the choice of plot size[13,33]. In small plots, the loss of trees is more disturbing than in large plots.

TABLE 8. COMPARISON OF MEAN RE (%) OF BREEDING TRIALS WITH DIFFERENT EXPERIMENTAL DESIGN

Character		SSCT simple lattice	LSCT simple lattice	LSCT balanced lattice	LSCT balanced incomplete blocks	LSCT overall mean
Yield/tree	a)	102.4 ± 2.2	108.4 ± 3.6	116.7 ± 12.3	119.9 ± 15.1	115.0 ± 5.9
	b)	100.3 – 104.9	103.5 – 111.7	102.3 – 136.0	105.4 – 151.4	108.4 – 119.9
	c)	4	5	7	9	3
Yield/ha	a)	-	113.5 ± 5.2	113.3 ± 10.9	112.3 ± 11.0	113.0 ± 0.6
	b)	-	106.7 – 120.4	104.3 – 136.5	100.4 – 134.9	111.2 – 113.5
	c)	-	5	7	9	3
Immature girth	a)	118.3 ± 16.3	122.0 ± 16.3	115.0 ± 10.8	-	118.5 ± 4.9
	b)	109.7 – 144.8	105.6 – 147.6	104.2 – 130.6	-	115.0 – 122.0
	c)	4	9	6	-	2
Mature girth	a)	107.6 ± 9.1	-	106.1 ± 8.7	128.4 ± 44.7	117.3 ± 15.8
	b)	100.2 – 126.8	-	100.0 – 121.2	100.1 – 221.7	106.1 – 128.4
	c)	7	-	5	7	2
Immature girth increment	a)	103.0 ± 2.9	118.0 ± 10.9	114.9 ± 7.4	-	116.5 ± 2.2
	b)	100.0 – 106.2	101.6 – 128.5	106.1 – 127.4	-	114.9 – 118.0
	c)	4	4	6	-	2
Girth increment on tapping	a)	111.3 ± 2.1	112.4 ± 12.1	-	119.4 ± 36.0	115.9 ± 4.9
	b)	108.4 – 112.5	100.6 – 130.5	-	100.0 – 204.0	112.4 – 119.4
	c)	3	5	-	9	2

a = Mean and standard deviation
b = Range including minimum and maximum values
c = No. of data sets involved in estimation
Source: Tan[24]

CONCLUSIONS

From the above deliberations, the following can be drawn:

- Statistics play an important role in the planning, recording, analyses and interpretations of data in rubber breeding trials.

- Various experimental designs (complete and incomplete blocks) have been used and are found useful in small-scale and large-scale testing in breeding trials.

- In SSCT, trial CV values were reported to be around 8.9% – 26.3% while those for LSCT were around 4.3% – 15.9% for yield and girth characters. Trial CV values for yield were the highest followed by girth increment and girth in both SSCT and LSCT. Generally trial CV values for SSCT were higher than those for LSCT for corresponding characters. This is expected because of the smaller plot size and limited number of replications in the former. The trial CV values obtained in both trials are considered acceptable, indicating that breeding trials are reasonably reliable.

- In SSCT, RE in using simple lattice design relative to randomised block design is low in most cases presented, suggesting small gain in trial precision. However, about 9% of the total cases analysed were shown to have more than 20% gain in precision using simple lattice design.

- In LSCT, RE values in using complicated design (*e.g.* simple lattice, balanced lattice and incomplete block designs) over randomised block design were also generally low. Majority of the cases studied (73.1%) gave less than 20% gain in efficiency. 64.5% of the cases analysed showed less than 15% gain in efficiency. About 27% of the total cases showed more than 20% gain in precision.

- The findings of about 9% – 27% of the total cases studied so far having achieved more than 20% gain in efficiency with the more sophisticated experimental designs over the randomised block design indicate that use of the more sophisticated designs in rubber breeding trials merits consideration. Designs used should also preferably be resolvable as randomised block design if the need arises as unpredictable circumstances may prevent proper trial analyses as originally planned.

- A plot size ranging from six to twelve trees in single row plot has been adopted in SSCT. This is considered satisfactory for screening large numbers of widely variable genotypes produced from the breeding programme. If the need to improve trial precision and efficiency in SSCT arises, the plot size and shape together with experimental design could be re-examined.

- A minimum of 25–36 recording trees has been reported to be acceptable plot sizes for LSCT. Taking this and other considerations, one could use a plot size of around 60 in 'semi-square' plot with approximate area of 1.5 ha to 0.2 ha/plot as suggested by Paadekooper[17]. A plot size of about 60 trees may result in around 35 recording trees in the course of experiment taking into account of losses due to natural causes or thinning.

- Generally, a 'semi-square' plot was preferred, although long-narrow plot was shown to have lower variance in LSCT (Paardekooper[17]). Uneven distri-

Also large plots facilitate the visual evaluation of tree habit *etc.* Because of this, it was proposed that a plot size of 0.16 ha be maintained (approximately 60 trees at maturity, of which half are recording trees), although the results of these uniformity trials indicate that somewhat smaller plot size would be more efficient. Narayanan[18] also did a similar study using girth data of PBIG/GG 1 seedlings. He reported that about 25–49 recording trees would give approximate minimum variance; about 35–45 recorded trees in a plot are acceptable plot size for experiments on immature rubber. In another study, Narayanan[19] analysed data from yield, girth and bark of five LSCT using Koch and Rigney's method[35] to obtain a mean value for coefficient of soil heterogeneity of around 0.6 with a range of between 0.3 and 0.8 which was used to determine the optimum plot size for various combinations of the number of replications and the magnitude of the treatment difference to be detected. Narayanan[19] did not give specific recommendations as to the optimum size for LSCT, but did infer close agreement with earlier studies and considerations[14-18].

Plot and Block Shape

Paardekooper[17] studied plot and block shape using girth data from uniformity trials. He suggested that 'semi-square' plots and blocks were preferred to 'guarded plots' because they were always more efficient than long, narrow plots and blocks particulary when they run along one whole side of the experimental area. Block shape is also influenced by soil types and terrain of experimental sites, resulting in somewhat irregular shapes. Whatever the shape may be, the principle of minimising the variability within each block and maximising the variability among blocks should always hold.

Number of Replication and Sites

Limited study was done with appropriate number of replications and number of testing sites in LSCT for rubber. Narayanan[19] considered various combinations on the number of replications and the magnitude of the treatment differences to be detected in relation to plot sizes using data from LSCT. If 36–49 recorded trees (64–81 trees with about 0.15 – 0.18 ha/plot) were aimed, four to five replications would be required to detect true difference of 20% – 30% between treatments at 50% CV – 90% CV. These results indicate that current trial designs are acceptable in terms of plot size and number of replications.

Iyer[22] who studied site effects, clone-site interaction and within site replication components of error in LSCT gave the following proposal:

	Combinations		
No. of replications	1	2	3
No. of sites	10	9	8

He commented that these combinations in any one clone trial was able to detect a difference of 224 kg/ha/year for mean yield over five years between clones with 95% confidence. His proposal thus infers that if more sites were to be tested to cover variable environments, a reduction of the number of replications to a minimum of two replications may be made. However, in practice, rubber breeders would still prefer to maintain a trial with four to five replications to allow possible damages due to unpredictable incidences including wind, fire, *etc.* If required, certain replications may be used for the inclusion of other experimental treatments to maximise obtaining necessary information regarding clonal performance and associated problems.

REFERENCES

1. TAN, H. (1987) Stategies in Rubber Tree Breeding, *Improving Vegetatively Propagated Crops (A J Abbott, and R K Atkin, eds)*, 27 London: Academic Press Ltd.

2. MAAS, J.G J.A. (1918) Reliability of Field Experiments with *Hevea Arch Rubbercult*, **2**, 608

3 BISHOP, O.F., GRANTHAM, J. AND KNAPP, M.D. (1917) Probale Error in Field Experimentation with *Hevea Arch Rubbercult*, **1**, 335

4. TENGWALL, T.A. AND ZYLL, C.E. VAN DER (1929) The Calculation of Experimental Field Results in Rubber Cultivation. *Arch Rubbercult*, **13**, 601.

5. BARCLAY, C. and GRANTHAM, J. (1933). Statistical Methods in Field Experiments with rubber *Arch Rubbercult*, **7**, 219

6 MURRAY, R K S. (1934). The Value of a Uniformity Trial in Field Experimentation with Rubber. *J Agric Sci*, **24**, 177

7. POSTHUMUOS, G. AND UVEN, M.J. Van (1935) Vereffening van proefveldr esultaten in de rubbercultuur (statistical analyses of experimental results). *Arch Rubbercult*, **19**, 27.

8. PAGE, H.J. (1938). The Uses of Statistics in Field Experiments with Rubber Trees. *J Rubb Res Inst Malaya*, **8**, 197.

9. WESTGARTH, D.R. (1953) Methods of Improving Precision in *Hevea* Trials. *Arch Rubbercult* (extra number) May, 1953, 180.

10. NARAYANAN, R. (1966) Value of Covariance Analyses in Manurial Experiments on Rubber. *J Rubb Res Inst Malaya*, **19(3)**, 176.

11 NARAYANAN, R. (1968) Girth as a Calibrating Variate for Improving Field Experiments on *Hevea brasiliensis J Rubb Res Inst Malaya*, **20(3)**, 130.

12. NARAYANAN, R. (1970) Double Covariance Analyses in Manurial Experiments on *Hevea J Rubb Res Inst Malaya*, **23(1)**, 47.

13 WESTGARTH, D.R. (1953) Optimum Number of Trees per Plot in a Clone Trial. Memo on 11 June, 1953. *Rubb Res Inst Malaya Res Arch Docum No 56*, 35.

14. PAARDEKOOPER, E.C. (1959) Optimum Number of Trees per Plot. Memo dated 29th July, 1959. *Rubb Res Inst Malaya Res Arch Docum No 56*, 37.

15 PAARDEKOOPER, E.C. (1960) Variability in Clone Trials. Memo dated 25th April, 1960. *Rubb Res Inst Malaya Res Arch Docum No 56*, 43.

16. PAARDEKOOPER, E C (1964) Variability and Optimum Plot Size Memo dated 10 September, 1964. *Rubb Res Inst Malaya Res Arch Docum No 56*, 44.

17. PAARDEKOOPER, E.C. (1966) Results of Four Uniformity Trials to Determine the Influence of Plot Size and Shape on the Efficiency of Field Experiments in Rubber. *Rubb Res Inst Malaya Res Arch Docum No 56*

18 NARAYANAN, R (1965) Some Consideration in Deciding the Optimum Number of Recorded Trees in a Plot for Experiments on Immature *Hevea brasiliensis J Rubb Res Inst Malaya*, **19(2)**, 120.

19. NARAYANAN, R. (1974) Estimation of Optimum Plot Size for Clone Trials in *Hevea J Rubb Res Inst Malaya*, **24(1)**, 54.

20 NARAYANAN, R., P'NG TAT CHIN AND NG ENG KOK (1967) Optimum Number of Trees in Tapping Experiments on *Hevea* I. Half Spiral Alternate Daily Tapping with and without Stimulation. *J Rubb Res Inst Malaya*, **20(2)**, 80.

21. NARAYANAN, R., HO, C.Y, SUBRAMANIAM, S. AND JEYATHEVAN, V. (1974) Relative Efficiency of Simple Lattice Designs in Clone Trials in *Hevea J Rubb Res Inst Malaysia*, **24(1)**, 26.

22. IYER, G.C. (1973) *Rep Rubb Inst Malaysia 1973*, 164.

bution of variances and more efficient recording trees in guarded plots argue for 'semi-square' plot over long-narrow plot size.

- Suitable number of replications and sites in LSCT were considered in limited studies. Based on these studies, one may use Iyer's and Paardekooper's proposals as a guide. For LSCT with five to seven sites to be tested, a corresponding six to four replications would be preferred. For those with eight to nine sites to be tested, three to two replications are considered acceptable. The number of sites and environments for LSCT are very much dependent on the offer of land by plantation groups or small holdings. In addition, practical problems, such as availability of infra-structure for trial establishment, management and recording and funds for conducting experiments including travelling expenses may come into play in the choice of sites for conducting experiments. In principle, one may prefer a minimum of two to three replications over a large number of experimental sites of varying environments for clone adaptation and clone-site (genotype-environment) interaction studies which will influence the method and policy of planting recommendations of rubber planting materials.

- Apart from theoretical, and agronomic considerations, other practical problems concerning land, staff and availability of fund should be taken into account in the planning and execution of breeding trials.

- As data collection is one of the important factors in determining trial reliability and precision, breeding experiments should emphasise on the quality of experimental data. In this regard, it should be emphasised that the importance of tasking to confound as blocks in trial with appropriate experimental design to avoid confounding effects of tappers. In addition, a close co-operation of plantation management, field staff and experimenter is of utmost importance to ensure proper trial management and recording to minimise experimental errors, thereby, improving reliability of data collected.

- With the development of new field designs, statistical techniques such as generalised lattices of Patterson and William[36] and nearest neighbour analyses of Wilkinson *et.al.*[37], computers and versatile scientific softwares, it would be useful to explore new approaches to further improve experimental precision in rubber breeding trials in the future.

ACKNOWLEDGEMENTS

Acknowledgements are made to Dr Abdul Aziz S.A.Kadir, Director, RRIM, for permission to publish this paper, and to Dr P.K.Yoon, former Head of Plant Science Division and Mr.G.C.Iyer, former Head of Statistics Section, RRIM for comments and discussions. Thanks are due to the staff of the Breeding Group in conducting the trials, and to the staff in Statistics Section for data analyses. The co-operation of various co-operating estates and the RRIM Experiment Station are gratefully acknowledged. Encik Ramli Musa is also thanked for typing the manuscript.

Date of receipt: September 1993

Date of acceptance: June 1994

23 ROSSETTI, A G. AND PIMENTEL GOMES, F. (1987) A Method for the Determination of Optimum Plot Size in Experiments with Rubber Tree *(Hevea) J nat Rubb Res*, **2(3),** 135

24. TAN, H (1989) Unpublished Data. Rubber Research Institute of Malaysia.

25. ROSS, J.M. (1965) The Selection of the RRIM 600 Series Clones. *Rubb Res Inst Malaya Res Archs Docum No 42*

26. PAARDEKOOPER, E.C. (1961) Report on the RRIM 'Exchange Clones' Trials (1954 Collection) II. *Rubb Res Inst Malaya Res Archs Docum No 14*

27. PAARDEKOOPER, E.C. (1962) Report on Clone/Tapping and RRIM 700 Series Clones Trials (1960-61) I. *Rubb Res Inst Malaya Res Archs Docum No 16*

28. PAARDEKOOPER, E.C (1964) Report on the RRIM 'Exchange Clones' Trials (Group B Trials) III. *Rubb Res Inst Malaya Res Archs Docum No 25*

29. PAARDEKOOPER, E.C. (1964) Report on Clone/Tapping and RRIM 700 Series Clones Trials II. *Rubb Res Inst Malaya, Res Archs Docum No 30*

30 PAARDEKOOPER, E.C. (1965) Report on the RRIM 'Exchange Clones' Trials (Group B Trials) IV *Rubb Res Inst Malaya Res Archs Docum No 41*

31. SULTAN, M.O (1969) Report on RRIM 700 Series Clones Trials (Second and Third Selection). I. *Rubb Res Inst Malaya Res Archs Docum No 60*

32 COCHRAN, W.G. and COX, G.M. (1969). *Experimental Designs,* 2nd edition. New York: John Wiley and Sons, Inc.

33. PEARCE, S.C. (1955). Some Considerations in Deciding Plot Size in Field Trials with Trees and Bushes. *J Indian Soc Agric Statistics,* **7,** 23.

34. SMITH, H. FAIRFIELD (1938). An Empirical Law Describing Heterogenity in the Yields of Agricultural Crops. *J Agric Sc*, **28,** 1.

35. KOCH, E.J. AND RIGNEY, J.A. (1951). A Method of Estimating Optimum Plot Size from Experimental Data. *Agron J*, **43,** 17.

36. PATTERSON, H.D AND WILLIAM, E.R. (1976) A New Class of Resolvable Incomplete Block Designs. *Biometrika,* **63,** 83.

37. WILKINSON, G.N , ECKERT, S.R., HANCOCK, T.N. AND MAYO, O. (1983) Nearest Neighbour (NN) Analyses of Field Experiments. *J Roy Stat Soc* Series B (Methodological), **45(2),** 151.

APPENDIX 1.
EXPERIMENTAL DETAILS FOR SMALL-SCALE (SSCT) AND LARGE-SCALE CLONAL TRIAL (LSCT) USED FOR PRESENT DELIBRATION

Experimental detail	SSCT simple lattice	LSCT randomised block	LSCT simple lattice	LSCT balanced lattice	LSCT balanced incomplete blocks
No. of replications	2	4	2	5	4 & 5
No. of trials	4	8	5	12	9
No. of clones	256 – 625	6 – 10	100	16	13 & 21
No. of trees/plots	6 – 7	75 – 125	60 – 72	50 – 72	34 – 90
Plot size (ha)	0.015 – 0.019	0.14 – 0.28	0.15 – 0.20	0.14 – 0.17	0.09 – 0.20
Planting density (trees/ha)	445 – 447	359 – 513	445 – 447	373 – 450	399 – 598
Experimental area (ha)	17.47 – 19.42	3.36 – 11.5	29.38 – 46.74	10.70 – 13.70	4.45 – 17.00