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Relative Efficiency of Simple Lattice Designs in Clone Trials in Hevea

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The relative efficiency of simple lattice designs in relation to randomised block designs is discussed for five large-scale clone trials arranged as seventeen simple lattices and five small-scale trials arranged as seven simple lattices. The yield per tree and per hectare, girth and bark thickness were measured on a number of occasions, and 378 sets of data for large-scale trials and 72 sets of data for small-scale trials were analysed.

The gain in efficiency in large-scale trials from using simple lattice designs was nil in about 30% of the analyses, between 0 and 10% in 35% of the analyses and between 10 and 30% in 22% of the analyses. A gain in efficiency of 30% or more was in only about 12% of the analyses. The gain in efficiency in small-scale trials varied between 0 and 10% in 86% of the analyses, between 10 and 20% in 8% of the analyses and was more than 20% in only 6% of the analyses.

Simple lattice designs do not give much improvement in efficiency relative to the ordinary randomised block designs where the area covered by a single replicate is about 4 hectares.

Designs such as simple randomised blocks and latin squares are unsuitable when a large number of treatments or variates are involved, mainly because it is difficult to obtain uniform areas where all the treatments can be applied in one complete block. Incomplete block designs (YATES, 1936), where the plots are arranged in blocks or groups smaller than a complete replication, eliminate heterogeneity to a large extent. For experiments involving factorial treatments, a reduction in block size can be achieved by sacrificing all or part of the information on certain treatment comparisons by means of confounding. However, incomplete block designs are appropriate for experiments where all the treatment comparisons are of equal interest. Such designs include balanced and partially balanced incomplete blocks, lattices (balanced or partially balanced), lattice squares, Youden squares and quasi-latin squares.

Lattice designs, although introduced as an improvement over randomised blocks, have a similar field layout to the latter with an additional restriction regarding the allocation of treatments within replications. The number of treatments must be a square (say k^2) and they are arranged in such a way that the effect of blocks within replicates can be removed or isolated from the error mean square of the analysis of variance. These designs allow a more accurate comparison between treatments. The k^2 treatments are arranged in blocks of k treatments in each replicate. A lattice design with two replications is a simple lattice, with three replications a triple lattice and so on. A lattice with k^2 treatments requires $k + 1$ replicates for complete balance.

The main disadvantages of lattice designs (compared with randomised block designs) are that the number of treatments must be a square, statistical analysis is more complicated and greater difficulty is involved in estimating missing values. Data from lattice experiments can be analysed either as lattices or as randomised blocks, so that a measure of the relative efficiency can be made.

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TABLE 1A. EXPERIMENTAL DETAILS OF LARGE-SCALE TRIALS

Experiment	Planting distance (m)	Plot size (ha)	Date of Planting	Date of Budding	Cut-back Lattice Date	Design	Start of recording: Girth Lattice Date	Start of recording: Yield Group Date
E1	9.14 x 3.05	0.17 (5 rows of 12 points)		Aug.-Dec. 1957	A B Oct. 1957 C D Jan. 1958	Four 5 x 5 lattices (A – D) in two replications. Apart from three common clones, each lattice contains different clones.	All Nov.1959	1 May 1963 2 Nov. 1963
E2	6.10 x 3.05	0.16 (6 rows of 12 points)	Nov. 1955	Aug.-Dec. 1957	A B Nov. 1957 C Dec.1957-Feb. 1958 D Apr. 1958	As E1	A B Nov.1959 C Dec. 1959 D Feb. 1960	1 May 1962 2 Nov. 1962 3 May 1963
E3	9.14 x 2.44	0.15 (6 rows of 11 points)	Jul.-Oct. 1956	Aug.-Dec. 1957	A B Oct. 1957 C D Jan. 1958	As E1	A B Oct. 1959 C D Jan. 1960	1 Apr. 1964 2 Oct. 1964 3 Apr. 1965
E4	6.71 x 3.35	0.16 (6 rows of 12 points)		May 1958	A Jun. 1958 B Jul. 1958 C D Sep. 1958	As E1	A B Jun. 1960 C D Aug. 1960	1 Jun. 1963 2 Dec. 1963 3 Jun. 1964
E5	9.14 x 2.44	0.20 (contour planting)	Nov. 1955	Oct.-Dec. 1956	Dec. 1956 Jan. 1957	One 10 x 10 lattice in two replications.	Dec. 1958	Jan. 1962

TABLE 1B. EXPERIMENTAL DETAILS OF SMALL-SCALE TRIALS

Experiment	Planting distance (m)	Plot size (ha)	Date of budding	Design		
				Clone	Lattice	Replication
S1	9.14 x 2.44	1/74 6 planting points	Nov. 1954	441	21 x 21	2
S2	9.14 x 2.44	1/74 6 palnting points	Nov. 1955	625	25 x 25	2
S3	6.71 x 3.35	1/64 7 planting points	Nov. 1956	256	16 x 16	2
S4	6.71 x 3.35	1/74 6 planting points	Nov. 1957	484	22 x 22	2
S5 (1)	9.14 x 2.44	1/74 6 planting points	May 1958	169	13 x 13	2
S5 (2)	9.14 x 2.44	1/74 6 planting points	May 1958	169	13 x 13	2
S5 (3)	9.14 x 2.44	1/74 6 planting points	May 1958	169	13 x 13	2

TABLE 2A. GIRTH, YIELD AND BARK THICKNESS DATA EXAMINED IN LARGE-SCALE TRIALS

Experiment No.	No. of lattices studied	Girth (cm)	Yield	Bark thickness
E1	4	Second year from cut-back Fourth year from cut-back Second to fourth year girth increment Increment four years from commencement of tapping (16)	Annual yield for first five years of tapping Mean annual yield over five years of tapping Cumulative yield for first five years of tapping (56)	Virgin bark at commencement of tapping Virgin bark after three years' tapping Renewed bark after three years' tapping Renewed bark after six years' tapping (16)
E2	4	Same as for E1 (16)	Same as for E1; annual yield for the sixth year also included. (64)	Same as for E1 (16)
E3	4	Same as for E1 (16)	Same as for E1 (56)	Same as for E1 except last item omitted (12)
E4	4	Same as for E1 except last item omitted (12)	Same as for E1 (56)	Same as for E1 (16)
E5	1	Same as for E1 (4)	Same as for E1; annual yield for the sixth and seventh years also included. (18)	Same as for E1 (4)

Number of sets of data for each experiment within brakets

TABLE 2B. GIRTH, YIELD AND BARK THICKNESS DATA EXAMINED IN SMALL-SCALE TRIALS

Experiment	Girth and girth increment (cm)		Mean annual yield (g/tree/tapping) over 5 years	Bark thickness	
	Initial	After 5 years' tapping		Virgin bark	Renewed bark
S1	Nov. 1959, Jun. 1961	Jun. 1966	Jul. 1961 — Jun. 1966	Jun. 1961, Jun. 1966	Jun. 1962, Jun. 1964, Jun. 1966
S2	Oct. 1959, Jun. 1962	Jul. 1967	Jul. 1962 — Jun. 1967	Jun. 1962, Jul. 1967	Jun. 1963, Jun. 1965, Jun. 1967
S3	Nov. 1960, Jun. 1962	Jul. 1967	Jul. 1962 — Jun. 1967	Same as for S2	Same as for S2
S4	Nov. 1960, Oct. 1963	—	Oct. 1963 — Sep. 1968	Oct. 1966, Dec. 1968	Oct. 1964, Oct. 1966, Oct. 1968
S5 (1)	Aug. 1960, Jun. 1964	Jun. 1969	Jul. 1964 — Jun. 1969	Jul. 1967	Jun. 1965, Jun. 1966, Jun. 1967
S5 (2)	Same as for S5 (1)		Same as for S5 (1)	Same as for S5 (1)	Same as for S5 (1)
S5 (3)	Same as for S5 (1)		Same as for S5 (1)	Same as for S5 (1)	Same as for S5 (1)

In uniformity trials, it is possible to study the relative efficiencies of various types of designs in relation to randomised blocks by successively superimposing the other designs on the data. The relative efficiency of the first design relative to the second is the ratio of the second design's error mean square to that of the first design. The error mean square of the randomised block design is generally used as the standard to compare the relative efficiencies of other designs.

This paper discusses the improvement in efficiency obtained in simple lattice designs relative to randomised blocks designs for some large- and small-scale clone trials of *Hevea.*

EXPERIMENTAL

Details of the large-scale clone trials (Experiments E1 to E5) and small-scale trials (Experiments S1 to S5) are given in *Tables 1a* and *1b* respectively. A 5 x 5 simple lattice design was used in Experiments E1 to E4 and a 10 x 10 simple lattice in Experiment E5. Experiments E1 to E4 consisted of four separate lattices (coded A – D) while Experiment E5 had but one lattice. The lattices had different clones or treatments (apart from three common clones). Girth, yield and bark measurements were recorded on 25 – 30 centrally located trees, after allowing for adequate boundaries between plots, which varied in size between 0.15 and 0.20 ha *(Table 2a)*. The trees reached tappable stage (51 cm girth at 152 cm above the union) at different times due to differences in growth rates, but the cumulative yield takes these differences into account.

Simple lattice designs of 21 x 21, 25 x 25, 16 x 16 and 22 x 22 were used for Experiments S1 to S4 respectively, while the three sub-trials in Experiment S5 [S5(1), S5(2) and S5(3)] used a 13 x 13 simple lattice design. Each experiment contained a different family of clones, and full experimental details are given in *Tables 1b* and *2b.*

An example of the analysis of variance of a simple lattice design (see COCHRAN AND COX, 1959) using the data for girth increment from the second to fourth year for Experiment E3 (lattice B) is given in *Table 3.*

Eb and *Ee* denote the inter- and intra-block errors for the simple lattice. The weighting factor μ used to adjust the treatments is given by:

TABLE 3. ANALYSIS OF VARIANCE OF A SIMPLE LATTICE DESIGN FOR GIRTH INCREMENT BETWEEN SECOND AND FOURTH YEARS (EXPERIMENT E3, LATTICE B)

Source	d.f.	Sum of square	Mean square
Replications	1	0.0394	0.0394 NS
Clones (unadjusted)	24	123.9222	5.1634**
Blocks within replications (adjusted)	8	31.0748	3.8844**Eb*
Intra-block error	16	19.5772	1.2236*Ee*
Total	49	174.6136	—
Error for randomised block design	24	50.6520	2.1105

Weighing factor $\mu = [Eb - Ee]/[k(r - 1)Eb] = [Eb - Ee]/[5Eb] = 0.137$
Effective error $= Ee\,[1 + (rk\mu)/(k + 1)] = [1 + (10\,\mu/6)]Ee = 1.5029$
where r = number of replications
k = number of treatments per block
μ = weighting factor
Efficiency relative to randomised block design (%) = (Error for R.B. design x 100)/(Effective error for lattice)
= (2.1105)/(1.5029) x 100 = 140.4%
Gain in efficiency = 40.4%

TABLE 4. PERCENTAGE EFFICIENCY OF SIMPLE LATTICE DESIGN RELATIVE TO RANDOMISED BLOCK DESIGN FOR LARGE-SCALE TRIALS

Experiment	No. of lattices	Character	No. of sets of data	Mean	S.D.	C.V. (%)
E1	4	Girth (cm)	16	124.7	30.8	24.7
		Yield (g/tree/tapping)	28	111.6	12.6	11.3
		Yield (kg/ha/year)	28	116.2	20.0	17.2
		Bark thickness (mm)	16	121.9	32.7	26.9
		Over all characters	88	117.3	23.4	19.9
E2	4	Girth (cm)	16	125.3	37.1	29.6
		Yield (g/tree/tapping)	32	109.3	14.1	12.9
		Yield (kg/ha/year)	32	112.4	14.1	12.6
		Bark thickness (mm)	16	111.3	15.8	14.2
		Over all characters	96	113.4	20.4	18.0
E3	4	Girth (cm)	16	105.9	11.4	10.8
		Yield (g/tree/tapping)	28	104.4	6.7	6.4
		Yield (kg/ha/year)	28	116.5	25.9	22.2
		Bark thickness (mm)	12	102.9	3.9	3.8
		Over all characters	84	108.5	17.1	15.7
E4	4	Girth (cm)	12	117.7	22.5	19.1
		Yield (g/tree/tapping)	28	111.3	17.8	16.0
		Yield (kg/ha/year)	28	110.4	14.4	13.0
		Bark thickness (mm)	16	105.0	9.0	8.5
		Over all characters	84	110.7	16.3	14.7
E5	1	Girth	4	127.4	18.7	14.6
		Yield (g/tree/tapping)	9	108.2	11.1	10.2
		Yield (kg/ha/year)	9	111.7	10.3	9.2
		Bark thickness (mm)	4	105.1	6.1	5.8
		Over all characters	26	111.9	13.0	11.7
Over all experiments and all characters			378	112.5	19.4	17.2

$\mu = [Eb - Ee]/[k(r - 1)Eb]$

and the average effective error mean square is:

$Ee\,[1 + (rk\mu)/(k + 1)]$

where r is the number of replications and k is the number of treatments per block.

The efficiency of the simple lattice relative to a randomised block (R.B.) is given by:

(Error mean square for randomised block design x 100)/(Average effective error mean square for lattice design)

The relative efficiency should generally be adjusted for the degree of freedom of the two error variances (see COCHRAN AND COX, 1959), but adjustment is considered unnecessary in the trials examined here.

The error mean square for a randomised block design is the pooled error mean square of the inter- and intra-block errors of the simple lattice. If $Eb < Ee$, μ is taken as zero; there is no gain in efficiency from using the simple lattice design in relation to a randomised block.

RESULTS AND DISCUSSION

The efficiencies of the simple lattice designs relative to randomised blocks have been calculated for all the sets of data listed in *Tables 2a* and *2b*. Thus, *Table 4* gives for each of the large-scale trials the mean, standard deviation and coefficient of variation of the efficiencies of the four lattices under the categories of girth, yield (gram per tree per tapping), yield (kilogram per hectare per year) and bark thickness.

Girth. The efficiency of the simple lattice design in relation to the randomised block design for girth records varies between 106 and 127%, with the corresponding coefficient of variation being in the range of 11 to 30%.

Yield. Except for Experiment E3, the mean efficiencies differ only slightly whether yield is expressed as gram per tree per tapping or kilogram per hectare per year. The mean efficiency ranges between 104 and 117%, the variability in coefficient of variation being between 6 and 22%.

Bark thickness. The mean efficiency lies between 103 (Experiment E3) and 122% (Experiment E1), the coefficient of variation varying from 4 to 27%.

Over all characters. The mean efficiency in the different experiments ranges between 109 and 117%, with a corresponding coefficient of variation varying between 12 and 20%. The efficiency averages 113% (coefficient of variation about 17%) over the 378 sets of data in the five experiments.

Table 5 shows the number of occasions in which there is no gain in efficiency from using a simple lattice design relative to a randomised block. There is no gain in efficiency in 25 to 36% of the cases for Experiments E1 to E4, while it is only about 15% for Experiment E5. Over the five experiments, the gain in efficiency is zero in about 30% of the cases.

TABLE 5. NUMBER OF OCCASIONS WITH NO GAIN IN EFFICIENCY OF SIMPLE LATTICE DESIGN RELATIVE TO A RANDOMISED BLOCK DESIGN FOR LARGE-SCALE TRIALS

Experiment	No. of cases with no gain in efficiency	Total cases	Proportion (%)
E1	23	88	26.1
E2	24	96	25.0
E3	30	84	35.7
E4	27	84	32.1
E5	4	26	15.4
Total	108	378	28.6

Table 6 shows the frequency distribution of the efficiencies of simple lattice designs relative to randomised blocks for the different experiments, and *Figure 1* their frequency histograms. The distributions have an L-shaped pattern with high frequencies at the beginning and small frequencies at the end.

TABLE 6. FREQUENCY DISTRIBUTION OF THE RELATIVE EFFICIENCY OF SIMPLE LATTICE DESIGN FOR LARGE-SCALE CLONE TRIALS

Class interval	Frequency				Class interval	Frequency
	E1	E2	E3	E4		E5
100 — 110	48 (55)	59 (62)	67 (80)	58 (69)	100 — 105	10 (38)
110 — 120	9 (10)	15 (16)	5(6)	11 (13)	105 — 110	5 (19)
120 — 130	12 (14)	10 (10)	7 (8)	5 (6)	110 — 115	5 (19)
130 — 140	7 (8)	4 (4)	—	5 (6)	115 — 120	1 (4)
140 — 150	4 (5)	3 (3)	1 (1)	2 (2)	120 — 125	—
150 — 160	2 (2)	3 (3)	2 (2)	—	125 — 130	2 (8)
160 — 170	1 (1)	—	—	3 (4)	130 — 135	1 (4)
170 — 180	3 (3)	—	1 (1)	—	135 — 140	1 (4)
180 — 190	1 (1)	1 (1)	—	—	140 — 145	—
190 — 200	—	—	1 (1)	—	145 — 150	1 (4)
200 — 210	—	—	—	—	—	—
210 — 220	—	—	—	—	—	—
220 — 230	1(1)	—	—	—	—	—
230 — 240	—	1 (1)	—	—	—	—
Total	88 (100)	96 (100)	84 (100)	84 (100)	—	26 (100)

Percentage frequencies within brackets

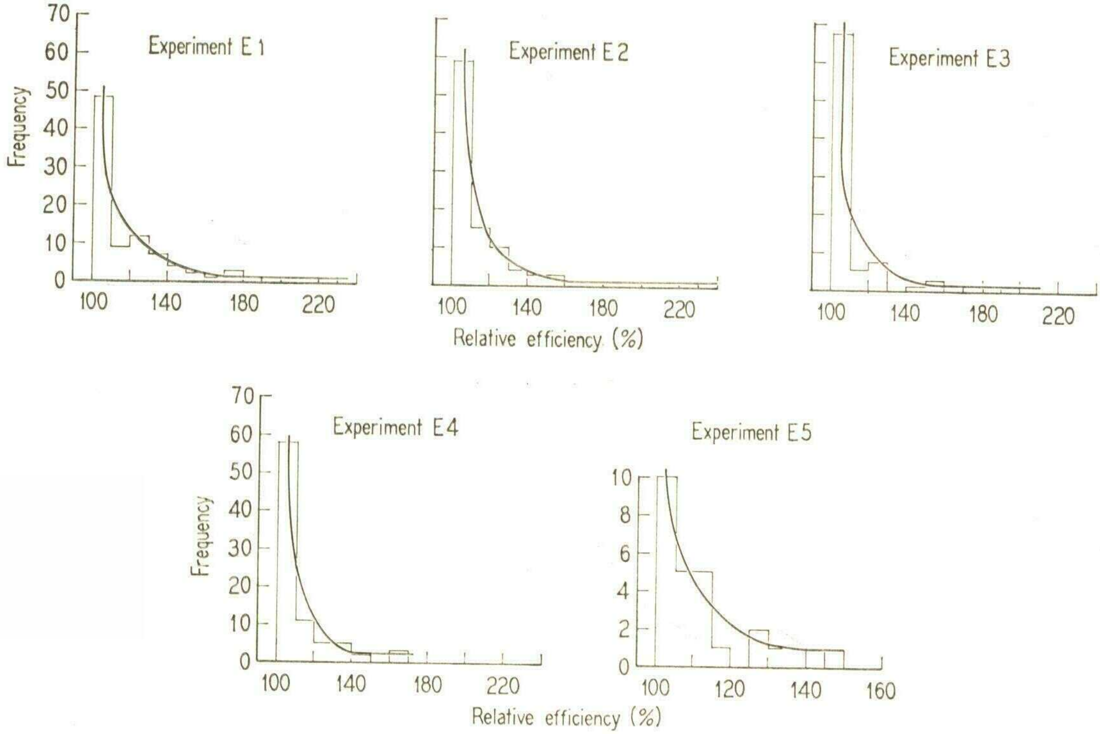

Figure 1. Frequency histograms of the relative efficiencies of simple lattice designs for five large-scale clone trials.

Table 6 shows that for all the experiments except E3 the gain in efficiency is below 10% in 55 to 69% of the cases and for E3 it is below 10% in about 80% of the cases.

The gain in efficiency is between 10 and 30% in about 22% of the occasions over all five experiments, and in only 4% of cases is a gain in efficiency of 50% or more attained. In two isolated instances the gain in efficiency exceeded 100%.

Figure 2 shows the percentage cumulative frequency distribution of the relative efficiencies for each experiment. The average gain in efficiency is less than 20%.

Figure 3 illustrates the year-by-year relative efficiencies for the yield data of Experiments E2 and E5. In the former experiment there is no consistent pattern with time, but in Experiment E5, the data of the sixth and seventh years show somewhat higher efficiencies relative to the first five years.

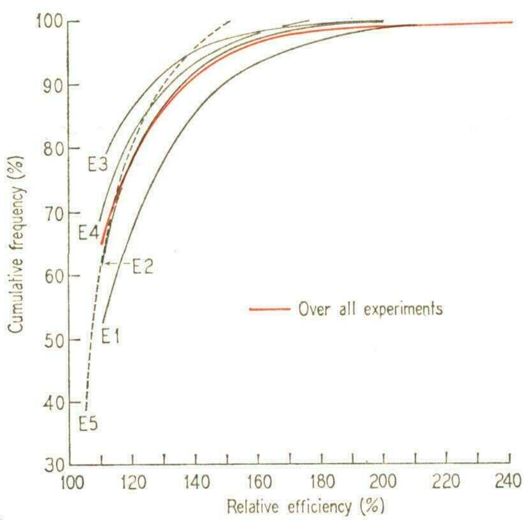

Figure 2. Percentage cumulative frequency distribution of the relative efficiency of simple lattice designs for five large-scale clone trials.

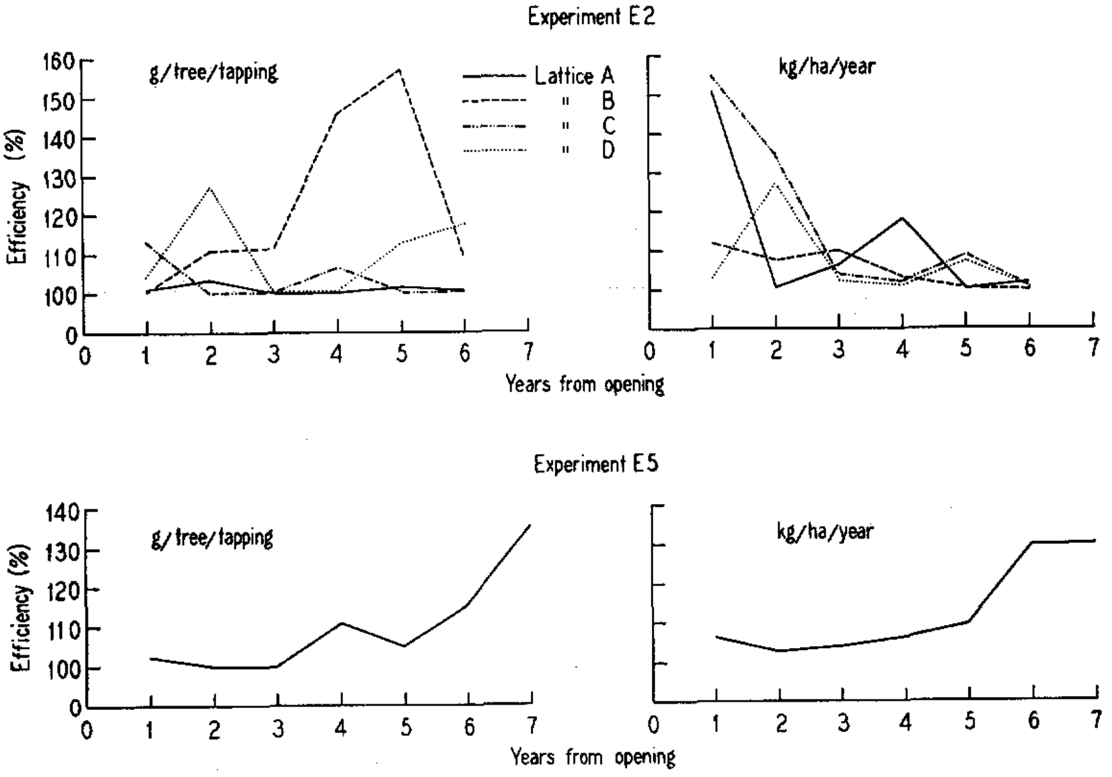

Figure 3. Trend of relative efficiency of simple lattice designs for annual yield data from Experiments E2 and E5.

The relative efficiencies in the small-scale trials are summarised in *Table 7.* The mean relative efficiency for the different trials varies between 101.8 and 109.3%, the corresponding range in the coefficient of variation being 2.1 to 12.0%. Over all the trials (seventy-two sets of data), the mean efficiency is about 106% (coefficient of variation 7.4%).

The frequency distribution of the relative efficiency data in the all small-scale trials indicates that in 86% of cases the gain in efficiency is below 10%, in 8% of the cases it is between 10 and 20% and that only in two isolated cases [Experiment S1 and S5(1)] does the gain in efficiency approach 40%.

CONCLUSIONS

The gain in efficiency in using simple lattice designs relative to the ordinary randomised block designs is small. For large-scale trials the gain in efficiency is zero in about 30% of the 378 cases and on average it is below 10%. The gain in efficiency lies between 10 to 30% in about 22% of the cases and a gain of 50% or more is attained only in about 4% of the cases. Even in Experiment E5 (a 10 x 10 simple lattice) the gain in efficiency of 25% or more is attained only in about 20% of the analyses.

For small-scale trials the gain in efficiency is below 10% in about 86% of the cases; more than a 20% gain is achieved in only 6% of the cases.

TABLE 7. PERCENTAGE EFFICIENCY OF SIMPLE LATTICE DESIGN RELATIVE TO RANDOMISED BLOCK DESIGN FOR SMALL-SCALE TRIALS

Experiment	Character	No. of sets of data	Mean	S.D.	Coefficient of variation (%)
S1	Over all characters	11	109.3	13.2	12.0
S2	,,	11	107.8	3.8	3.5
S3	,,	11	105.6	7.7	7.3
S4	,,	9	103.7	3.2	3.1
S5 (1)	,,	10	109.1	11.2	10.3
S5 (2)	,,	10	102.0	2.1	2.1
S5 (2)	,,	10	101.8	2.2	2.2
Over all characters and experiments		72	105.7	7.9	7.4

For large-scale trials having a plot size of 0.16 ha where a single replication is about 4 ha (*i.e.* twenty-five plots of 0.16 ha), the improvement in efficiency of the simple lattice relative to the randomised block appears to be small. FEDERER (1955) has suggested that if the gain in efficiency is less than 15%, no adjustment for block effects need be made and the data can be analysed as randomised blocks. Thus, for experiments involving large numbers of treatments, the field lay-out may be a lattice design and the data analysed either as a lattice or randomised block, depending on the relative efficiency attained on any occasion.

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