SIZE AND SHAPE OF PLOT IN RICE REPLICATED FIELD EXPERIMENTS

By

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As enumerated by Fisher (1950, 1951), statistical inquiries, whether theoretical or experimental, are in the areas of specification, estimation, and testing of hypothesis.

Designed and undesigned comparisons are covered in some detail in the area of the design and analysis of experiments involving mostly the problem of testing statistical hypotheses (Fisher, 1951; Kempthorne, 1952; Cochran and Cox, 1957). Determination of optimum size and shape of plot and block, and optimum combination of number of replications and number of samples per plot for efficient experimentation, involve the problem of estimation (Smith, 1938). One may also include the development of efficient sampling techniques as applied to each, or combination of characteristics of the rice plant, as falling also under this second category (Chang and Wang, 1962). The pattern or distribution of say, stem borer infestation may be included in the areas of specification and estimation (Kono and Sugino, 1958; Israel and Vedamutry, 1963; IRRI Annual Report, 1963; Oñate, 1964).

This paper will present statistical techniques and results on the application of these techniques in the estimation of optimum size and shape of plot from rice uniformity data and rice replicated field experiments and in the solution of number of replications needed for a desired level of precision.

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SIZE AND SHAPE OF PLOT IN RICE REPLICATED FIELD EXPERIMENTS

1. Estimation of optimum plot and size in uniformity trial and replicated field experiments

A block or field is planted to a common variety for uniformity trial. The purpose of this uniformity trial is to estimate optimum plot size and shape for efficient field experimentation. Optimum plot size will depend on soil variability and the various costs or relative efforts which enter into the various steps of field experimentation. Another source of information will be the analysis of variance (ANOV) from replicated field experiments which will be reconstructed in order to simulate uniformity data and thus give estimates of variability and an index of soil heterogeneity.

1.1. *Uniformity Trial*

An experimental block was planted to Peta rice seedlings on May 31, 1962 from seeds planted April 24, 1962. The distance between rows was 30 cm. (0.3 m.) and the distance between single plant hills was 20 cm. (0.2 m.). Weight of clean grain from a basic unit (b.u.) of 11 hills (a row length of 2.2 m.) was recorded. Data were adjusted for missing hills. There was a total of 87 rows, and each row contained 11 b.u. or a total of 957 b.u.

1.1.1. Statistical approach. The variability of variance (V) of the b.u.'s is given by

$$(V) = \left[\sum_{i=1}^{N} (X_i - \mu)^2\right] / (N-1),$$

where

(X_i) is the grain yield of the *i*th b.u.,

μ is the overall mean, and

N is the overall number of b.u.'s.

If x b.u.'s were chosen at random from N to form each plot of size x then the variance of the plot mean $(\bar{x})$ is the usual

$$V(\bar{x}) = (V)/x. \qquad \text{(Eq. 1)}$$

If, however, we form plots by using adjacent b.u.'s, there will be a tendency for the b.u.'s in the plot to be correlated. In this case, $V(\bar{x})$ will be larger than for a purely random case. With correlation within the plot,

$$V(\bar{x}) = (V)/x^b \,, \qquad \text{(Eq. 2)}$$

where

b is the index of soil variability and is between zero and one.

This relationship was established by Smith (1938) and has been found applicable and useful in many crops (Robinson, Rigney, and Harvey, 1948; Brim and Mason, 1959).

By taking logarithms, Eq. 2 is reduced to a linear form

$$Y(\bar{x}) = v - b\, n(x) \,, \qquad \text{(Eq. 3)}$$

where

$$Y(\bar{x}) = \log V(\bar{x}) \,,$$
$$v = \log (V)$$

and

$$n(x) = \log x \,.$$

The value of b is obtained by either a visual estimate from the linear relationship (Eq. 3) or by the least squares procedures. This index of soil heterogeneity will differ from characteristic to characteristic and the cost functions will behave likewise. The optimum plot size will be based on the optimum size for the most important characteristics. If the costs which enter the cost function are assumed constant for a given characteristic irrespective of variety, cultural practices, etc., then the value of b for each of the experimental blocks in the field becomes the most important single variable in the estimation of optimum plot size.

1.1.2. Experimental results. Different sizes and shapes of basic units were studied. The sizes and shapes are shown in Table 1. The values of b corresponding to Field Layout I to Field Layout V are shown in Table 2.

Table 1

SIZES AND SHAPES OF BASIC UNITS

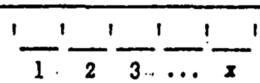
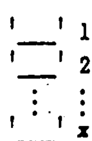
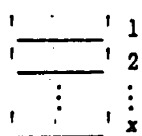
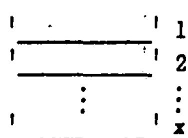
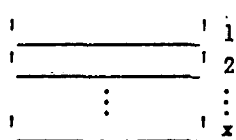
Field layout	Size	Shape	Basic unit (b.u.)
I	(1 row . x b.u.)		11 hills (2.2 m.)
II	(x rows . 1 b.u.)		11 hills (2.2 m.)
III	(x rows . 1 b.u.)		22 hills (4.4 m.)
IV	(x rows . 1 b.u.)		33 hills (6.6 m.)
V	(x rows . 1 b.u.)		44 hills (8.8 m.)

Table 2

VALUES OF OPTIMUM SIZE x_0, FOR DIFFERENT TYPES OF BASIC UNIT AND VARYING RATIOS OF $C_0/C_{b.u.}$

Field layout	Value of b	$C_0/C_{b.u.}$	Optimum plot size x_0
I			
(1 row · x b.u.) b.u. = 11 hills	0.2403	1	0.3
		2	0.6
		5	1.6
		10	3.2
		15	4.7
		20	6.3
II			
(x rows · 1 b.u.) b.u. = 11 hills	0.4071	1	0.7
		2	1.4
		5	3.4
		10	6.9
		15	10.3
		20	13.7
III			
(x rows · 1 b.u.) b.u. = 22 hills	0.1329	1	0.2
		2	0.3
		5	0.8
		10	1.5
		15	2.3
		20	3.1
IV			
(x rows · 1 b.u.) b.u. = 33 hills	0.1048	1	0.1
		2	0.2
		5	0.6
		10	1.2
		15	1.2
		20	2.3
V			
(x rows · 1 b.u.) b.u. = 44 hills	0.0864	1	0.1
		2	0.2
		5	0.5
		10	0.9
		15	1.4
		20	1.9

1.1.3. Cost function. If x is the size of the plot relative to a given basic unit (b.u.), then the cost of this x size plot is

$$x\, C_{b.u.}$$

where

$C_{b.u.}$ is the cost of a basic unit.

In addition to this variable cost, there is an overhead cost, C_0, which represents the cost or effort in using one plot irrespective of size. Thus, if an experiment will require M_x plots, each of size x, then the overall cost, C is:

$$C = M_x \ (C_{b.u.} \ x + C\ ) \ . \qquad \text{(Eq. 4)}$$

1.1.4. Optimum plot size. Following the usual argument, we want to minimize the variance,

$$V(\bar{x}) = V_{b.u.} / x^b \ \ M_x \qquad \text{(Eq. 5)}$$

with respect to x, subject to the condition that the total fixed cost, C, is

$$C = M_x \ (C_{b.u.} \ x + C_0) \ ,$$

where

$C_{b.u.}$ = cost of taking the observations, recording, tabulating and computations,

and C_0 = cost of locating the plot, moving from plot to plot and overhead costs.

The optimum solution is

$$x_0 = [b / (1 - b)] \ \ (C_0 / C_{b.u.}) \qquad \text{(Eq. 6)}$$

which is more or less the form reported in the literature (Abraham and Mohanty, 1955; Brim and Mason, 1959).

For each of the five Field Layouts and for varying ratios of $C_0/C_{b.u.}$, the corresponding values of x_0 are shown in Table 2.

Assume that $C_0/C_{b.u.} = 5$, then from Table 2, our optimum plot size will be

(4 rows x 11 hills),
(1 row x 22 hills),
(1 row x 33 hills),
and (1 row x 44 hills)

for layouts I to V, respectively. These plot sizes are relatively small, even if we consider that guard rows and guard hills will be provided for in each experimental plot of size x. The variance and cost functions may include a term involving these guard rows or hills. Data given in Tables 3 and 4 show the ranges of the coefficient of variability (cv) in percent for different sizes and shapes of plot. For variety Peta (Table 3), the cv is 48 percent for a 2-row x 11 hills

Table 3

RANGE OF THE COEFFICIENT OF VARIABILITY (σ/μ) IN PERCENT FOR DIFFERENT COMBINATIONS OF NUMBER OF ROWS AND NUMBER OF BASIC UNITS. UNIFORMITY DATA ON GRAIN YIELD. VARIETY PETA. IRRI. 1962.

(Block T - 6)

Number of row	Number of basic units*		
	1 (11 hills)	2 (22 hills)	3 (33 hills)
2	48 (1.32)**	44 (2.64)	43 (3.96)
3	46 (1.98)	44 (1.98)	42 (5.94)
4	45 (2.64)	43 (5.28)	41 (7.92)
8	43 (5.28)	41 (10.56)	40 (15.84)
12	42 (7.92)	41 (15.84)	40 (23.76)

*One basic unit is equivalent to 11 plant hills.

**Figure in ( ) is area of plot in sq.m. and distance of planting is 0.3 m. between rows and 0.2 m. between hills.

(1.32 sq.m.) and the cv is 40 percent for a 12-row x 33 hills (23.76 sq.m.). For variety BPI-76 (Table 4) the cv ranges from 21 percent for a 2-row x 8 hills (1 sq.m.) to 15 percent for a 12-row x 36 hills (27 sq.m.) plot.

Table 4

RANGE OF THE COEFFICIENT OF VARIABILITY (σ/μ) IN PERCENT FOR DIFFERENT COMBINATIONS OF NUMBER OF ROWS AND NUMBER OF BASIC UNITS. UNIFORMITY DATA ON GRAIN YIELD. VARIETY BPI-76. IRRI. 1963.

(Block M-14)

Number of row	Number of basic units*			
	2 (8 hills)	3 (12 hills)	6 (24 hills)	9 (36 hills)
2	21 (1.00)**	20 (1.50)	17 (3.00)	18 (4.50)
3	20 (1.50)	18 (2.25)	17 (4.50)	18 (6.75)
4	19 (2.00)	18 (3.00)	16 (6.00)	16 (9.00)
8	17 (4.00)	17 (6.00)	15 (12.00)	16 (18.00)
12	17 (6.00)	13 (9.00)	15 (18.00)	15 (27.00)

*One basic unit is equivalent to 4 plant hills.

**Figure in ( ) indicates the area of the plot and the distance of planting is .25 m. x .25 m. (.0625 sq.m.).

The reduction in cv is gradual and slow even for larger sizes of plot. The results given in Tables 2, 3 and 4 indicate that smaller plots, say, 4 rows x 12 hills (5 to 6 sq.m.) will be as efficient as larger plots. In addition, with smaller sizes plot, more local control is applied which results in a lower experimental error. Consequently, one can use more replications within the same field area. The precision of field experiments at IRRI for 1963 was a cv($\bar{X}$) of about 10 percent.

Note that the slow and gradual decrease of the cv for the larger sized plots is explainable by the relation,

$$V(T/x) = V/x^b$$

$$V(T)/x^2 = V/x^b$$

$$V(T) = Vx^2/x^b.$$

where

$$T = \sum_j^x Y_j ,$$

x is the size of the plot ,

and

b is the measure of soil heterogeneity.

Since

$$cv(T) \doteq \sqrt{V(T)} / \mu x ,$$

then

$$cv(T) = \sqrt{V}\ x/\mu x\ x^{b/2}$$
$$= (\sqrt{V}/\mu)\ x^{-b/2}$$

or

$$cv(T) = cv(b.u.)\ x^{-b/2} .$$

We have observed that in Table 2 the value of b will range from 0.1 to 0.4 which implies that for each type of b.u. the value of $x^{-b/2}$ will range from

$$x^{-.40/2} \quad \text{to} \quad x^{-.10/2}$$

or

$$(1/x)^{1/5} \quad \text{to} \quad (1/x)^{1/20}$$

Even for $x = 12$ as given in Tables 3 and 4, the multiplier of cv (b.u.) will be

$$(1/12)^{1/5} \quad \text{to} \quad (1/12)^{1/20}$$

or

$$0.58 \quad \text{to} \quad 0.88$$

For a b.u. of 11 hills (Table 3), the ratio of the cv's for $x = 12$ rows is 42/48 (0.87), for 22 hills the ratio is 41/44 (0.93), and for 33 hills the ratio is 40/43 (0.93). In Table 4 the ratio of the cv's is 17/21 (0.81) for 8 hills, 13/20 (0.65) for 12 hills, 15/17 (0.88) for 24 hills, and 15/18 (0.83) for 36 hills. These results imply that b is close to 0.1 for almost all of the b.u.'s. This low value of b will explain the slow and gradual decrease in cv for the larger sized plots. Of course, the value of b may be obtained by least squares using all possible points.

1.1.5. Other considerations.

Sampling. Yield of grain and yield of straw are usually collected on a plot basis although at times, individual samples from a plot are resorted to in reporting these characteristics. Plant height, number of tillers, number and length of panicles, and many other plant characteristics are recorded on a plant or hill basis. Often these characteristics are collected on a sample basis from the plot. In these cases, the $V(\bar{x})$ will consist of at least two components, one of which is the sub-sampling variance. The model for this sampling scheme will be considered in another paper.

Guard rows. The overall cost given in Eq. 4 does not include the cost of providing guard rows or the perimeter of the experimental plot. This cost and other costs may have to be considered in working for an optimum solution. However, even if we increase the optimum plot size to say $2x_o$, this will not materially affect the variability requirement for the optimum.

Many characteristics. As indicated earlier, each characteristic will exhibit a different value of b, a different ratio $C_0/C_{b.u.}$, different efficiency of sampling and different weights regarding priority. In view of these requirements, a compromise optimum plot size is usually resorted to in a specific manner. The optimum plot size is solved for the most important characteristic, say, grain yield. Into this plot size is designed or interwoven, sampling schemes which will elicit at minimum cost the maximum amount of information for the other characteristics.

1.2. *Estimation in Replicated Field Experiments*

Data from replicated field experiments may also be used to extract additional information in the determination of optimum size and shape of plot. The technique involves reconstructing the ANOV for the particular replicated field experiment in order that it will simulate uniformity data (Koch and Rigney, 1951).

For example, in a split-split design with sub-sampling in the ultimate plot, the expected mean square (EMS) for replications, Error (a), Error (b), Error (c) and sampling error may be compared to their respective EMS from uniformity data. This comparison is given in Table 5. Note that the ANOV for the uniformity data is similar to that for a hierarchical classification with replications, whole plots, sub-plots, sub-sub-plots, and sub-sub-sub-plots (samples within ultimate plots) as the smallest unit. There will be five estimates of $V(\bar{x})$ per basic unit, one estimate for each plot size x. With the use of Eqs. 1, 2, and 3, we can have an estimate of b for this particular replicated field experiment. This estimate of b is used to obtain the number of replications (r) needed to detect a given difference (d) at varying size of plot (x) for the succeeding experiment (see Eq. 8). Also, the problem of a weighted estimate of b must be considered. Some of the approaches to this problem are given by Smith (1938) and Hatheway and Williams (1959).

Table 5

COMPARISON OF COMPONENTS OF VARIANCE IN A SPLIT-SPLIT PLOT DESIGN AND UNIFORMITY DATA

ANOV

Split-Split plot		Uniformity data			
SV	DF	SV	DF	MS	EMS (Infinite Model)
Reps (r)	$(r-1)$	Reps (r)	$(r-1)$	E_1	$\sigma_5^2+s\sigma_4^2+sc\sigma_3^2+scb\sigma_2^2+scba\sigma_1^2$
A	$(a-1)$				
Error (a)	$(r-1)(a-1)$	Whole plots w/in reps	$r(a-1)$	E_2	$\sigma_5^2+s\sigma_4^2+sc\sigma_3^2+scb\sigma_2^2$
B	$(b-1)$				
AB	$(a-1)(b-1)$				
Error (b)	$a(r-1)(b-1)$	Sub-plots w/in whole plots	$ra(b-1)$	E_3	$\sigma_5^2+s\sigma_4^2+sc\sigma_3^2$
C	$(c-1)$				
AC	$(a-1)(c-1)$				
BC	$(b-1)(c-1)$				
ABC	$(a-1)(b-1)(c-1)$				
Error (c)	$ab(r-1)(c-1)$	Sub-sub-plots w/in sub-plot	$rab(c-1)$	E_4	$\sigma_5^2+s\sigma_4^2$
Sampling error	$rabc(s-1)$	Sub-sub-sub-plot w/in sub-sub-plot	$rabc(s-1)$	E_5	σ_5^2

One of the experiments conducted by the Department of Agronomy, International Rice Research Institute and which contains elements for the estimation of optimum plot size is given below:

Replication -- Three
Whole Plots -- Three Water Treatments
1st Split -- Varieties Chianung 242 and FBI 121
2nd Split -- Four Nitrogen Levels
3rd Split -- Two Sub-samples
Size of Plot -- 1 m. X 5 m. (5 rows X 25 hills)
(b.u.) Characteristic -- Yield of clean grain per b.u.

Koch and Rigney (1951) reported zero components of variance in their study of data from tobacco experiments. If there are no zero components, the E's will be adjusted to a $V(\bar{x})$ on a per basic unit basis and the linear relationship between log $V(\bar{x})$ and log plot size x will again be used to estimate b using Eqs. 1 to 3. Note that in the experiment described above the size of the b.u. is 5 rows X 25 hills (1 m. X 5 m.). This model is presently being tested on a series of experiments designed in such a manner as to elicit the required information for the estimation of b, the index of soil heterogeneity.

II. Number of Replications for Tests of Significance

The rule of finding the number of replications (r) required for a given probability (P) of obtaining a significant result is given by Cochran and Cox (1957, pp. 18-22) in the form

$$r = 2(t_1 + t_2)^2(\sigma/d)^2 \quad \text{(Eq. 7)}$$

where

r is the number of replications required

σ is the true standard error per unit as percent of the mean

d is the true difference that is desired to be detected

t_1 is the significant value of t in the test of significance

t_2 is the value of t in the ordinary table corresponding to $2(1-P)$, and

P is the probability of obtaining a significant result.

Since t_1 and t_2 depend on t, then an iteration procedure may have to be necessary until the smallest r is obtained.

Applied research workers are interested in the specifications required of the experiments rather than the costs or efforts. The question posed by Hatheway (1961) concerned the element of convenience of obtaining a plot size which will meet the specifications given in Eq. 7. By using

$$V(\bar{x}) = (V)/x^b$$

in Eq. 7, two relationships are obtained, namely:

$$r = 2(t_1 + t_2)^2(K^2/d^2x^b) \qquad \text{(Eq. 8)}$$

and

$$x^b = 2(t_1 + t_2)^2(K^2/d^2r)\ , \qquad \text{(Eq. 9)}$$

where

$$K^2 = (V)/\mu^2$$

is the coefficient of variation of the basic unit in percent. The other symbols were defined in the previous equations.

In Eq. 8, we can solve for r using the x_0 and b obtained from Table 2. The solution for r (Eq. 8) or for the convenient size x (Eq. 9) will depend also on the knowledge of K and d.

In either case, the solution for r, the number of replications (Eq. 8) or the solution for x, the convenient plot size (Eq. 9) hinges on some reliable estimate of K, the coefficient of variability and on b, the index of soil heterogeneity. It is desirable, therefore, to have stable estimates of K and b from uniformity data or from replicated field experiments in order that estimates of r or x will also be stable. Applications of these techniques to grain yield and panicle weight of the rice plant are given by Oñate (1964).

Another important relation which may be used as guide of research workers is the relation

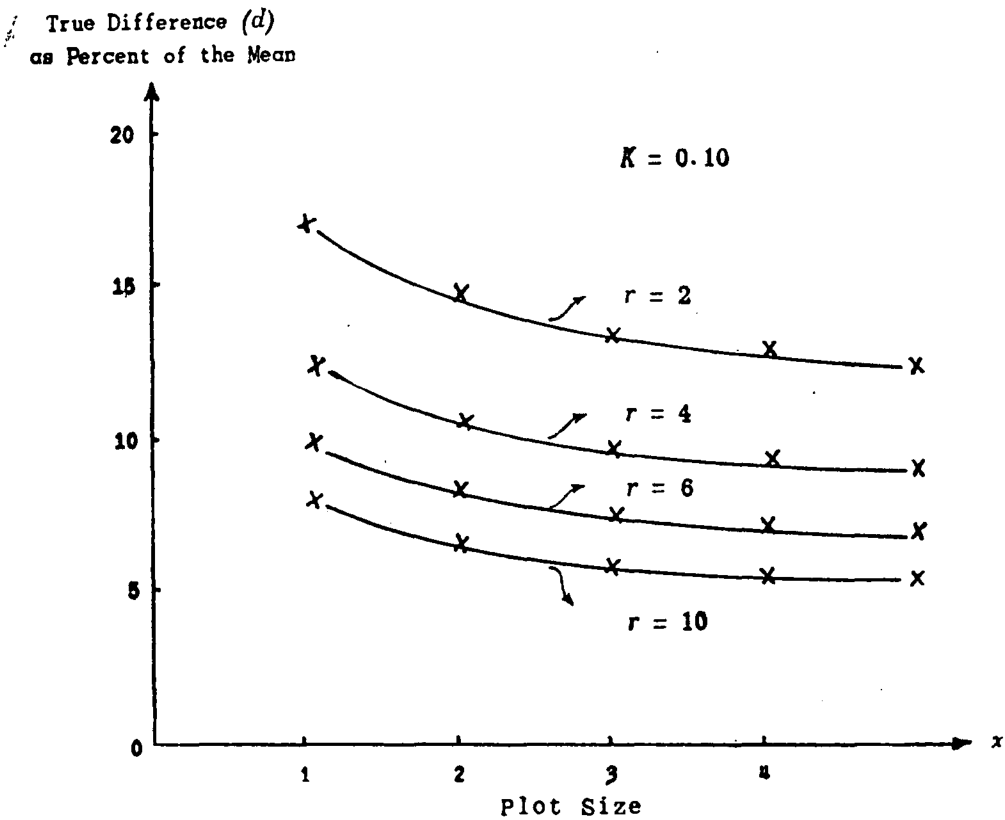
$$d^2 = 2(t_1 + t_2)^2(K^2/rx) . \qquad \text{(Eq. 10)}$$

Figure 1 shows the relationship between d and varying values of r and x for $K = 0.10$, $b = 0.4$, $a = .05$, $P = 0.80$ and $t = 11$ treatments. The average K for field experiments at the Insti-

Figure 1

EFFECT OF PLOT SIZE (x) AND NUMBER OF REPLICATIONS (r) ON THE TRUE DIFFERENCE (d) AS PERCENT OF THE MEAN (μ)

($b = 0.4$, $t = 11$, $a = 0.05$, $P = 0.8$)



tute in 1963 was about 10 percent. Depending on the levels of K and b, convenient combinations of r and x may be used at the desired level of d. Note that the solutions from previous replicated field experiments for x_0 and b may be used for d^2 where x_0 is a multiple of the ultimate plot and b is between zero and one (Fig. 1; Eq. 10). If a plot size of 4 rows x 12 hills (an area of about 3 sq.m.) is used, then by application of local control our $K = .10$ (10 percent) may be reduced to about $K = .05$ (5 percent). In this case, we can set the true difference (d) as percent of the mean (μ) at a lower level, say, 5 percent instead of 10 percent, and the number of replications needed will still be about 5 replications.

Thus, with a reduction in K, we can detect smaller differences with the same number of replicates, assuming that the solution for x_0 is

$$x_0 = 4 \text{ rows} \times 12 \text{ hills (about 3 sq.m.)}$$

The nature of the curves for $r = 4$ to $r = 10$ is so gradual that it is not advantageous to increase x_0 to say $2x_0$.

III. Summary and Discussion

The paper discusses some statistical approaches to the problem of estimation for optimum plot size and shape for rice replicated field experiments, from uniformity data and also from particular set of replicated field experiments. Then the criteria of minimum variance or efficiency and cost are combined with the criterion of convenience to solve for the number of replications needed for a desired precision.

Results indicate that the use of the linear relationships between log variance and log plot size as proposed by Smith (1938) is reasonable. The tests were applied on uniformity data and on data simulating uniformity data from rice replicated field experiments. From these tests were evolved a series of estimates of b which, when used with the appropriate ratio $C_0/C_{b.u.}$, will give a series of estimates of optimum plot size (x_0). It is highly desirable that the design of the experiments contains some element of sectionalizing the data to be collected in order to elicit information on the sub-plot. sub-sub-plot and the ultimate sampling units desired. The solution to the problem of number of replications for tests of significance is obtained from this estimate of b for succeeding experiments. Stable solutions hinge on reliable estimates of K, the coefficient of variability and b. the index of soil heterogeneity.

Results indicate that plot of dimensions x_0 = 4 rows x 12 hills (about 3 to 5 sq.m.) will be relatively as efficient as bigger sized plots for field experiments on rice. This size may be enlarged to about $2x_0$ depending on the cultural, management, and sampling requirements without materially affecting the optimum solution. The precision of field experiments at the Institute for 1963 as measured by the coefficient of variation of a single observation $K = [cv(X)]$, is about 10 percent. This implies that we need about 5 replicates in order to detect a mean difference of 10 percent. If more local control is instituted, we can reduce K to 5 percent and with 5 replicates, we can detect mean differences of 5 percent of the mean. The models used in this paper may be extended to studies on rice crop cutting experiments (Oñate, 1962).

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