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THE EFFICIENCY OF PRE-EXPERIMENTAL YIELD IN THE CALIBRATION OF COCONUT EXPERIMENTS

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The coefficient of variation of experiments with mature coconut palms in respect of the character 'yield' varies from 11% to 15% when the plot size varies from 18 palms to 6 palms.

The experimental precision is higher in years when the cropping intensity is high. There is also a tendency for the experimental precision to improve as the experiment ages and with increased plot size.

With the use of pre-experimental yield as a calibrating variate the experimental error can be reduced by 30% to 50%. Two year's pre-experimental yield brings about a higher reduction in experimental error than using one year's, and using more than two year's pre-experimental yield does not help. In fact when one takes into consideration the delay caused by keeping pre-experimental records, and the cost involved, one year's pre-experimental records could be considered the optimum.

In view of the fact that even with 6-palm plots, the coefficient of variation can be kept within 10% with the aid of calibration, there is a strong case for reduction of plots size in coconut experiments.

INTRODUCTION

The use of some prior information pertaining to a given experimental material, to control (by statistical means) its variability during the experimental phase, has been aptly termed 'Calibration' by Pearce (1953). It has been amply demonstrated by Pearce (1969), Pearce & Taylor (1950), Pearce and Brown (1960), and Vernon & Morris (1964), that this technique can contribute in a very large measure to the success of field experimentation on perennial crops, helping as it were to reduce by half or more the high inherent variability which has very often been a source of frustration to research workers.

The calibration approach to increased precision is being exploited freely in the analysis of experimental data at the Coconut Research Institute of Ceylon and with a considerable amount of success too. In a young plantation, the experimental error for the character 'Yield' was observed to be as high as 66% and the use of suitable calibrating variates helped to effect a reduction of this error by 85% (Abeywardena 1964). In experiments with adult palms, by the use of a single year's pre-experimental yield, the reduction in the experimental error was in the range 25% to 60% (Abeywardena—unpublished).

In Ceylon, coconut experiments are usually laid down on the larger plantations, which are generally pretty uniform with regard to age and spacing of palms. Consequently and with the added advantage of using a plot size of 18 palms, which on current standards can be considered pretty large, the coefficient of variation (i.e. precision) of our experiments has remained within a respectable range of 10% to 18%. This plot size of 18 palms recommended by Peiris & Salgado (1937) for the pioneer field experiments on coconut, although arrived at by plotting the coefficients of variation against plot size, can still be considered arbitrary when viewed in the light of the classical arguments put forward by Fairfield Smith (1938). Anyway now that it is known that calibration can improve experimental precision considerably, it is opportune to review the problem of plot size in coconut experiments. Can the plot size be reduced sufficiently taking advantage of calibration methods, while still keeping experimental precision within efficient limits? With the high cost of field experimentation on tree crops and the resultant curtailment of experiment programmes, an early answer to this question is of great importance to research progress.

MATERIALS & METHODS

The data used in this analysis were the individual palm nut yields of a uniformly maintained block of 300 adult coconut palms—the block being of a type encountered normally in coconut experiments. The yields were available over a period of 19 consecutive years—namely 1936 to 1954. The yields from 1955 todate were avoided as some of the palms in this block have been used for pollination purposes during this period.

The analysis consisted of simulating a randomized block design with six dummy treatments allocated at random to the plots within each block. A plot was a cluster of palms of a given plot size, without any particular emphasis on the shape of the plot. Six such adjacent plots constituted a block. On these lines, separate randomized block designs were simulated for plot sizes of six, eight, ten and twelve palms. Plot sizes below six palms were not considered as it has been suggested that the minimum plot size for coconut experiments should be about six, if biennial effects are to be kept under reasonable control (Abeywardena 1965). It may also be informative to point out that in the formation of the randomized block designs, the number of blocks had to be reduced for the larger plot sizes. This was inevitable as the number of palms available was only 300. Accordingly there were 7 blocks for 6 palm plots, 5 blocks for 8 palm plots, 4 blocks for 10 palm plots and 3 blocks only for 12 palm plots.

The efficiency of pre-experimental yield as a calibrating variate is determined using the same technique adopted by Vernon & Morris (1964). That is by calculating the correlation coefficient r(p i q) between a set of plot yields aggregated over a period of p consecutive years (denoting the calibrating variate) and the yields of the same plots within a subsequent period of q consequtive years (denoting the experimental variate), "i" being the gap in years between the calibrating variate and the experimental variate.

In the present analysis, q was restricted to a single year, in keeping with a suggestion (Abeywardena 1963) that analysis of coconut experiments has to be done for each year separately. "p" however varried from 1 to 4 years, in order to ascertain to what extent calibration would be more efficient when an aggregate of more than one year's pre-experimental yield is used. The present study also differs from that of Vernon and Morris in that their r(p i q)'s refer to the total correlation between plots, whereas in this study randomized block designs were simulated and the correlation coefficients were calculated using the error variance and covariances as is customary in the actual application of the calibration technique.

2736 such r(p i q)'s indicating efficiency of calibration were calculated and have been summarized as done by Vernon and Morris (1964) in the form of correlation matrices—one each for every p $\times$ plot size combination. For a given plot size and given p, the correlation matrix will contain, in each row, the successive correlations between each moving aggregate of p years and the subsequent single years. Accordingly 16 such correlation matrices are available.

Within each correlation matrix, the correlations do not differ appreciably except in a very few instances. Moreover within a given matrix, their degrees of freedom are the same. Therefore a simple averaging of these coefficients without resorting to the "z" transformation may be satisfactory.

RESULTS

1. PRECISION OF COCONUT EXPERIMENTS WITHOUT CALIBRATION

(a) Average precision of coconut experiments

The precision of an experiment is given by the coefficient of variation (i.e.–$\sqrt{\text{Error M.S.}}$/mean per plot)—the precision being higher when the coefficient of variation is low and vice versa.

The mean coefficient of variation for coconut experiments is approximately 13% for plot sizes ranging from 6 palms to 18 palms, and the coefficients range from about 8% to 20% (Table 1). Gauged against the experimental precision pertaining to other tree crops reported in the literature, coconut experiments do not seem to suffer from a prohibitively high variability.

(b) Fluctuations of precision in different years

In experiments with perennial crops, large fluctuations in precision in the different years can give rise to problems in the interpretation of data.

TABLE 1—The frequency distribution of the coefficients of variation in different years

Plot size	*No. of years with coefficient of variation*							*Mean C. of V.*
	10%	12%	14%	16%	18%	20%	20%& over	
6-palms	0	4	4	5	3	3	0	14.6%
8-palms	4	6	4	4	1	0	0	12.0%
10-palms	0	3	4	4	4	3	2	15.4%
12-palms	4	8	4	2	1	0	0	11.5%
*18-palms	0	10	6	3	0	0	0	11.7%

**Information from another experiment.*

As indicated by the range of the coefficients of variation for a given plot size (Table 1), the precision of a coconut experiment can differ appreciably in different years. However, in this Institute, such changes in precision did not give rise to difficulties in the interpretation of results, such as, for instance, a particular treatment effect being significant in one year and not so in another. One reason for this may be that we have been using 18-palm plots throughout and as seen from Table 1, the range of variation of the precision is small for 18-palm plots.

(c) Influence of cropping intensity and age of experiment on Experimental precision

The changes that take place in an experiment in different years are mainly in respect of cropping intensity, such changes being the result of short term fluctuations due to the weather and also a possible time trend as the experiment ages. It would be of interest to examine whether the fluctuations of experimental precision in different years are in any way associated with changes in cropping intensity and also whether the experimental precision itself exhibits any time trend on its own.

A series of linear correlations have been calculated (Table 2) between mean yield per plot (x_1) indicating cropping intensity, age of experiment (x_3) and coefficient of variation (x_2) indicating experimental precision.

TABLE 2—Correlations between mean yield per plot (x_1) coefficient variation (x_2) and age of experiment (x_3)

Correlation Coefficient	*Plot size*			
	6 palms	*8 palms*	*10 palms*	*12 palms*
$rx_2\ x_1$	−0.4115	−0.6172	−0.4075	−0.1729
$rx_2\ x_3$	−0.4892	−0.2374	−0.1227	−0.4481
$rx_2'\ x_1\ (x_3)$	−0.6450	−0.7321	−0.4626	−0.0531
$rx_2\ x_3\ (x_1)$	−0.6820	−0.5568	−0.2677	−0.4165

Most of the correlation coefficients are not significant. Yet their repetition at a similar level and direction for various plot sizes may be considered sufficient evidence to be suggestive of an association.

The correlation ceofficients between mean yield per plot and the coefficient of variation are negative. It appears therefore that the experimental precision is high for years with higher cropping intensities. However this dependence of experimental precision on cropping intensity appears to decrease for higher plot sizes.

The correlation coefficients between coefficient of variation and age of experiment are negative and are variable for different plot sizes. The experimental precision thus shows a slight tendency to improve with the passage of time.

As the cropping intensity itself shows a slight tendency, ($rx_1\ x_1$) to decrease with age of experiment, partial correlations have been calculated ($rx_2x_1.x_3$ and $rx_2x_3.x_1$). The relationships observed earlier are in fact shown with greater emphasis in the partial coefficients.

(d) Association between experimental precision and plot size

TABLE 3—Mean coefficients of variation for different plot sizes

Plot Size	*Mean Coeffi. of Va.*	*Range of c.of v.*
6-palms	14.6%	10.6−19.9
8-palms	12.0%	8.5−17.6
10-palms	15.4%	10.4−21.2
12-palms	11.5%	7.6−16.0
18-palms*	11.7%	10.0−15.0

**Information from another experiment.*

As shown by the mean coefficients of variation for different plot sizes (Table 3), there appears to be a tendency for the coefficient of variation to decrease i.e. the precision to increase with increasing plot size. However, this trend is not so consistent as one would reasonably expect it to be. The coefficient of variation is high for 6 palm plots, slightly lower for 8-palm plots, high again for 10-palm plots and for 12-palm plots lower than that for 8-palm plots.

This irregular feature may not be the result of the number of replicates differing for the different plots-sizes, because the number of replicates dropped steadily from seven for 6 palm plots to three for 12-palm plots and also because the coefficient of variation is independent of the number of degrees of freedom in the error variance. Therefore it can be safely assumed that the irregular trend of the coefficients of variation is mainly, incidental to the method adopted in forming the blocks in the dummy designs—that is, due to our not adhering to a particular shape of plot or block orientation.

2. RELATIVE EFFICIENCY OF PRE-EXPERIMENTAL YIELD AS A CALIBRATING VARIATE.

(a) Efficiency of calibration as p increases

The efficiency of calibration can be measured by the coefficient of determination i.e. the square of the correlation coefficient. It indicates by what fraction the experimental error would be reduced through calibration. Such coefficients of determination ($\bar{r}^2$), each based on the mean of 171 r's in each p × plot size correlation matrix are shown in Table 4.

TABLE 4—Coefficients of determination for each p × plot size combination

Plot size	*Coefficient of Determination for p equal to*			
	1 year	*2 years*	*3 years*	*4 years*
6-palms	0.4892	0.5703	0.5851	0.5932
8-palms	0.4185	0.5265	0.5479	0.5489
10-palms	0.7135	0.7674	0.7702	0.7754
12-palms	0.5721	0.6480	0.6616	0.6532

It is clear from Table 4 that calibration is more efficient when more than a single year's pre-experimental yield is used. Two years aggregate of yields as the calibrating variate is superior to a single year, but there is hardly any worthwhile improvement to be expected from the use of aggregates of more than two years' pre-experimental data.

This pattern of the increasing efficiency of calibration as p increases, is similar for experiments with different plot sizes.

(b) Relative efficiency of calibration as plot size increases

For a given p, the expected consistent increase in the efficiency of calibration with increasing plot size is not clearly brought out in Table 4. Calibration seems to be more efficient with 6 palm plots, less efficient with 8 palm plots, again more efficient with 10 palm plots, and less efficient with 12 palm plots.

This apparently meaningless trend of calibration efficiency with increasing plot size, brings out an interesting feature in calibration. A comparison with Table 3, shows that for plot sizes where the coefficient of variation was large (i.e. where the experimental precision was low) the coefficient of determination is also large and *vice versa*. This is undoubtedly a very helpful feature as far as experimental practice is concerned. When experimental precision is low (say) either due to lowered plot size or due to an unfavourable orientation of blocks or shape of plots, this is counter-balanced to some degree or other by a high coefficient of determination, resulting in the maintenance of a favourable level of experimental efficiency.

Such a self-adjusting tendency in calibration has been reported by Vernon (1961), where he observes that in respect of place to place variation, the adjusted variances may be less variable than the unadjusted variances, high r values tending to be associated with high initial error. Vernon & Morris (1964) commenting on this observation have however stated that the evidence is too slight to be conclusive.

3. ABSOLUTE EFFICIENCY OF PRE-EXPERIMENTAL YIELD AS A CALIBRATING VARIATE.

In the earlier section, the efficiency of calibration was gauged by r^{-2} which indicates what fraction of the experimental error variance is held in control by the calibrating variate. This was termed "relative efficiency".

This index of relative efficiency, though widely used, is not the best index of the efficiency of calibration due to the fact that there appears to be an association between r^2 and the unadjusted variance. It is more expressive to get an index of "absolute efficiency" such as the coefficient of variation based on the adjusted error variance. In fact as Vernon & Morris (1964) also point out, what is relevant to experimental needs is the adjusted variance itself rather than the proportion of the adjusted variance controlled by calibration.

The square of the mean r for each $p \times$ plot size combination is used to calculate the adjusted variances for each year. The coefficients of variation derived from the latter are averaged over the years 1938-1954 and indicated in Table 5.

TABLE 5—Mean adjusted coefficients of variation

Plot size	*Mean adjusted c of v*			
	p = 1	p = 2	p = 3	p = 4
6-palms	10.4%	9.5%	9.4%	9.3%
8-palms	9.3%	8.4%	8.2%	8.2%
10-palms	8.4%	7.5%	7.5%	7.4%
12-palms	7.7%	6.9%	6.8%	6.9%

It is clear that the experimental precision after calibration improves steadily with increasing plot size. It is also demonstrated that using more than 2-years' pre-experimental yield as the calibrating variate is not at all justified.

The operation of the self-adjusting property of calibration is also clearly brought out. The variable trend of the experimental precision (Table 3) and also of the coefficients of determination (Table 4) have interacted among themselves to give a very regular form in the ultimate result (Table 5).

Through the aid of calibration, the experimental precision has improved considerably. The coefficient of variation is in the 10% range even for 6 palm plots.

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