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Impact of Covariate on Single Palm Plot Experiments in Coconut

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Abstract

The most robust design in field experiments of coconut is the randomized complete block design (RCBD) with plot size of six palms. It has now become a serious problem in finding homogenous blocks for experiments in coconut and therefore a single palm plot has been recommended by the authors. This study found that single palm plot with covariate as pre yield data is the most suitable method to reduce the unknown variability of coconut palms based on analysis of data of seven concluded field experiments on cultural management and fertilization of coconut with plot size of six palms. The percentage reduction of CV in single palm plot with covariate with respect to single palm plot without covariate varied from 21% to 60% irrespectively location, period and type of the experiment. The percentage reduction of CV in single palm plot with covariate with respect to six palm plots without covariate was 40% to 71%. Thus single palm plot is recommended for field experiments in coconut except under special circumstance such as for coconut based farming system trails (CBFS).The methodology developed to select single palm from the concluded experiments with plot size more than one can easily be applied for similar studies in other tree crops.

Keywords: Coconut, field experiments, covariate, RCBD, single palm plot.

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Introduction

Unlike other plantation crops coconut palms have very high variability between palms in a given location. Thus in designing field experiments for coconuts, both experimenters and biometricians have to face many practical problems in selecting suitable sites. The most commonly used and robust design in coconut experiments has been identified as the randomized complete block design (RCBD) with a plot size of six palms (Peiris and Thattil, 1977). However, due to high variability between and within trees in a plot and block, selecting the plot size of six trees has been a problem for the researchers.

In a recent study (Kularatne *et al.* 2006), it had been shown that the number of palms per plot can be reduced from six to one without changing the original inferences in designing field experiments in coconut. Further, it was shown that the coefficient of variation with single palm has reduced substantially compared to that of plot of six palms. However, in their study the effect of covariate on the precision of the experiments on single palm plot experiment has not been investigated.

In an efficient experimental design, it is necessary to minimize the unexplained variability in experiments as far as possible to avoid bias of the inferences derived. In the cases blocking alone may not be able to achieve adequate control of experimental error. Thus the experimental error can be further reduced more effectively by applying covariance analysis technique using proper covariate. Further, covariance analysis can be considered as an additional benefit to interpretation of experimental results as it adjusts the treatment means due to the influence of pre treatment effect (Samita, 1992).

Many authors have revealed that the precision of the field experiments in tree crops can be improved considerably through the aid of covariate (Pearce, 1953; Abeywardena, 1970; Abeysinghe, 1986; and Wijesuriya and Thatill, 1996). In coconut experimentations Abeywardena (1970) found that the coefficient of variation of an experiment with six palms plots can be reduced by 4.2% by taking pre-experimental data for one year as a covariate. However, no studies were reported about the effect of covariate on single palm plot for experimentation in coconut. Nevertheless, some scientists have studied single palm plot design with covariate to increase the precision of the other tree crops (Correll and Cellier, 1987; Brun, 1997; Montagnon *et al*., 2001; Lachenaud and Montagnon, 2002).

Therefore, the objective of this study is to find the impact of covariate on single palm plot experimentations in coconut with respect to the precision and final inferences using secondary data from concluded field experiments in coconut.

Materials and methods

Secondary data

The individual nut yield record of coconut palms from seven concluded multi-location field experiments were selected from field experiment database maintained by the Biometry Division, CRI. Among different yield parameters of coconut such as weight of copra, number of female flowers and number of leaves etc, the nut yield per palm was taken as the response variable in this study, as it is the significantly most important variable to compare the treatments. The design of all experiments was RCBD with a plot size of six. Blocking was done on visual observations of the soil properties of the land in consultation with the experimenter when the land is flat and uniform. Otherwise blocking is done based on soil variation or gradient of the experimental area as identified or at least strongly suspected, as in terms of soil slope, internal drainage, soil classes etc. However, we take the only past data from the conducted experiments and data are selected randomly within blocks, how blocks have been done does not affect on our results. Basic properties of each design are given in Table 1. The details of each experiment are given in Appendix A.

Selection of single palm within a plot

As there are 18 plots of six palms in the experiment 5, 6^{18} combinations of single palm can be selected without changing the number of blocks. However, as computing the large number of combinations is not feasible in statistical software, two palms within a plot were selected randomly and combinations of these two palms were used in the computation. With two palms per plot, 6^{18} combinations were reduced to 2^{18} combinations. This way of palm selection was done due to limitation of computational problem, and the methodology is well explained by Kularatne *et al*, (2006). The typical pattern of the selected palms is shown in Figure 1. The ANOVA was carried out and least square estimates were obtained for each combination of 2^{18} for other experiments as well (Cochran and Cox, 1957).

Methodology used

The analysis of covariance (ANCOVA) is a technique that combines the features of ANOVA and regression under the assumption that the response variable is linearly correlated with the covariate. The inclusion of covariates can be increased the statistical power of the experiment and so it improves the precision of the experiment. The mathematical additive model for covariance analysis under RCDB can be written as,

$$y_{ij} = \mu + \beta_i + \tau_j + \rho(x_{ij} - \bar{x}) + \varepsilon_{ij}$$

where, y_{ij} = observed nut yield per palm of the plot receiving the jth treatment in the ith block,

μ = overall mean,

τ_j = effect of the j^th treatment (j = 1, 2, .. t),

β_i = effect of the i^th block (i = 1, 2, ….. b),

x_{ij} = covariate (yield per palm prior to application of treatment) the plots receiving the j^th plot in the i^th block,

$\bar{x}_{..}$ = common mean of the covariate,

ρ = the regression coefficient of y_{ij} on x_{ij},

ε_{ij} = random variability (experimental error) independently distributed as $N(0, \sigma)$ and the parameters satisfy

$$\sum_{i=1}^{b} \beta_i = 0 \text{ and } \sum_{j=1}^{t} \tau_j = 0.$$

The coefficient of variation was computed for each year of the experiment with covariate for the purpose of comparing the efficiency. The number of occurrence of significant covariate was also computed. The computed CV with covariate for the original design was compared with the mean CV obtained under all combinations of single palm design with covariate. The changing pattern of significance of covariate was also compared between the original design (with six palms) and the design of the single palm with covariate. Analysis was performed using SAS software version 8 (SAS, 1999).

Results and Discussion

Analysis with plots of six palms

The CV obtained from the ANOVA for each year and location is given in Table 2.

According to the results in Table 2, it can be confirmed that out of 19 cases, significant difference between treatments was found only for three cases. Results further show that CV of each case is high irrespective of significant of treatment and varies from 26.3% to 39.9%.

Analysis with plots of single palm

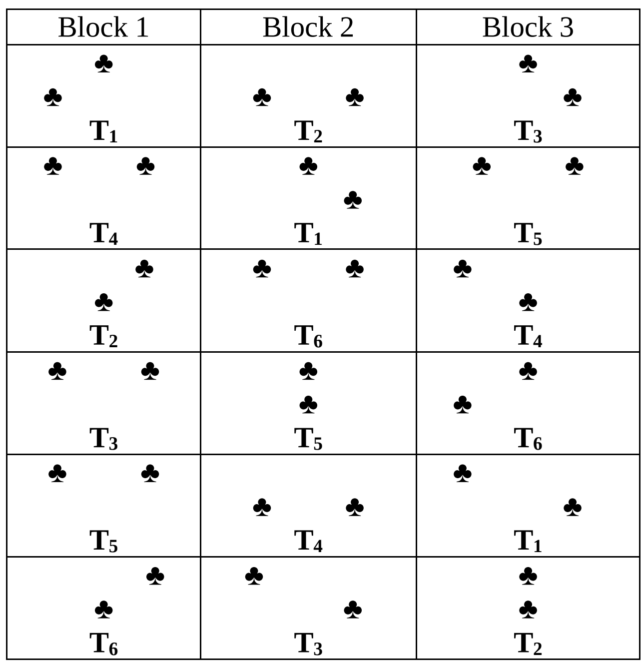
ANOVA was also carried out for all possible combinations of single palm plot (with the same number of blocks and treatment as for the original design) for a given year in each experiment. The mean CV of the all possible combinations for a given year and given location is shown in Table 3.

Table 1. Basic properties of the selected experiments

Experiment	Location	Period/Year	Number of	Plot

			blocks	treatments	size
1	Rathmalagara	1996-1999	3	5	6
2	Siringapatha	1996-1999	3	4	6
3	Thammanna	1996-1999	4	4	6
4	Wayagolla	1996-1999	4	4	6
5	Ambakelle	1997	3	6	6
6	Pottukullama	1997	3	6	6
7	Wayagolla	1998	3	5	6

Figure 1. Spatial position of two palms selected from each plot in a RCBD with 3 blocks and 6 treatments of experiment 5



♣ – Coconut palm and
T – Type of treatment

Table 2. CV of initial field plan with plot size of six and status of significant of treatment (response variable is nut yield per palm)

Experiment	Location	Year	Serial number	Status of significant	CV
1	Rathmalagara	1996	1	ns	26.4

		1997	2	ns	29.2
		1998	3	ns	33.3
		1999	4	ns	31.0
2	Siringapatha	1996	5	ns	27.2
		1997	6	ns	30.6
		1998	7	ns	29.7
		1999	8	ns	30.7
3	Thammanna	1996	9	ns	30.1
		1997	10	ns	31.0
		1998	11	ns	39.9
		1999	12	ns	37.2
4	Wayagolla	1996	13	ns	27.1
		1997	14	ns	26.3
		1998	15	ns	29.5
		1999	16	ns	29.4
5	Ambakelle	1997	17	*	31.2
6	Pottukullama	1997	18	**	30.1
7	Wayagolla	1998	19	*	28.7

*, ** indicates the significance at 5% and 1% respectively
ns – non significant

Table 3. Mean CV of the all combinations of single palm plot within each experiment (response variable is nut yield per palm)

Experiment	Location	Year	Serial number	Mean CV	Percentage of cases having single palm with treatment significant
1	Rathmalagara	1996	1	22.8	0.0
		1997	2	28.8	1.1
		1998	3	22.5	11.3
		1999	4	27.1	7.8
2	Siringapatha	1996	5	18.0	0.4
		1997	6	16.5	8.3
		1998	7	21.1	2.7
		1999	8	14.9	1.6
3	Thammanna	1996	9	29.3	0.8
		1997	10	26.4	0.7
		1998	11	38.8	0.0
		1999	12	36.2	0.0
4	Wayagolla	1996	13	26.0	0.1
		1997	14	25.8	0.9
		1998	15	27.3	12.9
		1999	16	27.2	3.2
5	Ambakelle	1997	17	17.4	93.4
6	Pottukullama	1997	18	21.1	82.7
7	Wayagolla	1998	19	20.2	90.5

When comparing the results in Table 2 and Table 3, it can be confirmed that CV of cases having single palm was significantly lower than the corresponding experiments with six palms. It indicates that the experimental error can be reduced by taking single palm plot irrespective of years and type of experiments. The percentage reduction of CV of single palm plot with respect to six palms plot varied from 0.4% to 15.8%.

Analysis further found that even though the plot size reduced from six to one without changing original design, the status of significance of treatments has not changed except three cases (serial number 3, 15 & 18). However, such a thing can be ignored as extremely higher number of combinations (>2x10^5) was considered for each case of single palm design. Thus it can be concluded that there is no difference of the inference obtained between plots of six palms and plots of one palm, in spite of additional cost to operate the experiments with six palms. In addition conducting an experiment with single palm plot is more practicable compared to plots with six palms.

Analysis of six palms plot with covariate

The six palms plot with covariate of the previous one year yield was used for the analysis. The CV obtained from the Analysis of Covariance for each experiment and year for six palm design is given in Table 4. The pre-recorded yield was used to analyze for the seven experiments except two. As the pre-data was not available in the two experiments that is experiment 1 and 2, post-data of the first year was converted to use as pre-data by removing block and treatment effects as suggested by Peiris and Thattil (1997).

Results in Table 4 show that the significant difference between the treatments was found only for three out of 17 cases. It can be confirmed that CV with covariate (non-significant cases) is high and varies from 22.2% to 38.7% and CV with covariate (significant cases) is low and varies from 12.4% to 16.1%.

It was found that all the covariates in the analysis were significant irrespective of the experiment. Results in Table 4 further indicate that there is no significant differences between treatments even thought covariate was used for the analysis. This could happen due to inefficient blocking. But when comparing the results in Table 2 and Table 4, the CV of six palms plot can be reduced by using untreated nut yield as covariate irrespective of years and type of experiments. It varied from 1.2% to 7.2% in treatment significant experiments and from 14.0% to 16.3% in the rest of the experiments. The percentage reduction of CV was substantially high in the significant cases. The average percentage reduction of CV of the six palms plot with and without covariate was 20% approximately irrespective of the experiment.

Analysis of single palm plots with covariate

Results in the Table 5 indicate that the mean CV of the all combinations of single palm plot with one covariate for each experiment. It varied from 8.5% to 18.2% irrespective of significant and non-significant cases. The reduction of CV of single palm plot (with covariate) with respect to six palm plot (without covariate) varied from 11.5% to 22.2% irrespective of experiment (Figure 2). It was shown that there was a significant change of CV between initial design (six palms plot) and one palm plots. The average reduction of CV between the single palm plot with one covariate and six palms plot was 18% approximately irrespective of the experiment. Comparing the Table 4 and 9, this figure with the covariate of six and single palm plot was 12% approximately. Therefore the inferences of the initial design changed supporting the interpretation of the field experiment when the size of the plot reduced six to one.

There was a high percentage reduction of CV of single palm with covariate with respect

Figure 2. Temporal variability of CV of six palm plot (without covariate) and single palm plot (with covariate) with reduction

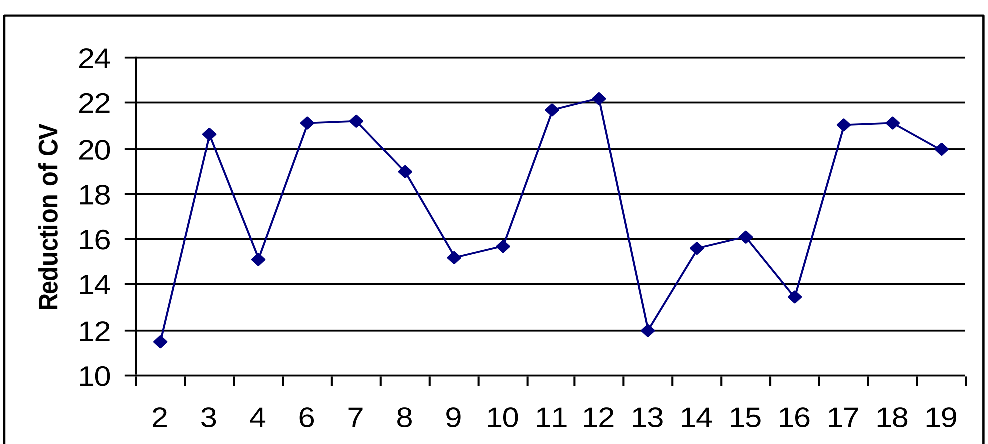


Table 4. CV of original design with six palm plot with one covariate and status of significant of treatment within each experiment and year (response variable is nut yield per palm and the covariate was nut yield per palm prior to application of treatment)

Experiment	Location	Year	Serial number	Status of treatment significant with covariate	Mean CV with covariate (six palms)
1	Rathmalagara	1996	1	-	-
		1997	2	ns	24.6
		1998	3	ns	26.5
		1999	4	ns	25.2
2	Siringapatha	1996	5	-	-
		1997	6	ns	25.1
		1998	7	ns	22.5
		1999	8	ns	27.0
3	Thammanna	1996	9	ns	28.4
		1997	10	ns	26.3
		1998	11	ns	38.7
		1999	12	ns	34.9
4	Wayagolla	1996	13	ns	25.9
		1997	14	ns	22.2
		1998	15	ns	24.3
		1999	16	ns	25.8
5	Ambakelle	1997	17	*	15.1
6	Pottukullama	1997	18	**	16.1
7	Wayagolla	1998	19	*	12.4

*, ** indicates the significance at 5% and 1% respectively
ns – non significant

Table 5. Mean CV of the all combinations of single palm plot with one covariate within each experiment and year (CV of covariate significant combinations) and % reduction with respects to single palm

Experiment	Year	Serial number	Mean CV with covariate	% reduction with single palm
1	1996	1	-	-
	1997	2	17.7	38.5
	1998	3	12.7	43.6
	1999	4	15.9	41.3
2	1996	5	-	-
	1997	6	9.5	42.4

	1998	7	8.5	59.7
	1999	8	11.7	21.5
3	1996	9	14.9	49.1
	1997	10	15.3	42.0
	1998	11	18.2	53.1
	1999	12	15.0	58.6
4	1996	13	15.1	41.9
	1997	14	10.7	58.5
	1998	15	13.4	50.9
	1999	16	15.9	41.5
5	1997	17	10.2	41.4
6	1997	18	9.0	57.3
7	1998	19	8.7	56.9

Table 6. Comparison of significant of covariate between six palms and one palm in percentage of 19 cases

Serial number	Status of significant with plot size of six palms	Percentage of cases having single palm with covariate significant
1	ns	-
2	ns	74
3	ns	83
4	ns	69
5	ns	-
6	ns	59
7	ns	60
8	ns	57
9	ns	91
10	ns	64
11	ns	66
12	ns	86
13	ns	91
14	ns	62
15	ns	83
16	ns	79
17	*	73
18	**	97
19	*	100

*, ** indicates the significance at 5% and 1% respectively
ns – non significant

to CV of single palm without covariate. The average percentage reduction of CV of the single palm plot with covariate compared to that of the single palm plot without covariate was 47%. It was also found that the average percentage reduction of CV of single palm plot with covariate as compared to six palms without covariate was 58%.

Results in Table 6 indicate that when the plot size was reduced from six to one without changing original design, the status of covariate significance of the model was around 70%. However this can happen because higher number of combination (>$2x10^5$) was considered for each case of single palm design.

In the six palms plot covariate analysis, the mean of six palms is used as pre-data and post-data for covariate in the experiment data. But the genetically inheritant, unexplained variability of a palm is completely different palm to palm. In other words the variability of a particular palm is extremely different from other palm. The mean of the six or more than one palm is meaningless in the technique of the covariance analysis. It is not beneficial to increase the precision of the experiment.

Considering the single palm plot size, it sufficiently meets with the individual inheritant characters in the palm for covariance analysis. That is all the inheritant variability of the palm is same in the analysis. Then the model can be captured only variability of field and treatment.

Technically single palm plot is more superior to the plots having more number of palms, from a blocking point of view as variability within a block is minimized for plot size of one palm compared with plot of more than one palms. More number of palms per plot is taken to reduce the variation among palms. But, for the analysis, the mean yield per palm based on palms with a plot is taken. Generally a plot consists of adjoining palms. Thus variability between plots within a block is higher. In contrast a single palm plot experiments, variability among plots within a block is comparatively low. However, if there is no limitation for the lands, and the experimenter feels that the number of palms is not sufficient, the best way is to increase the number of blocks with single palm plots. This is more efficient than increasing the plot size.

Another advantage is in single palm plot the plot shape can be kept uniform. In practice in designing field experiments, plot shapes (in square or rectangular plot) cannot be maintained uniformly due to many reasons in experimentation field. Thus single palm plot is superior to plots having more number of palms.

The unpredictability of pest, diseases, drought and lightning strikes under field conditions, causing the lost of single experimental palms. As such, this means very costly in terms of efforts, time and other resources. However, such damage could happen not only to single palm, it could happen to single plot or whole block. Further, when there is single palm data collection will be much easier than that for more number of palms per plot. Thus, from a practical point of view also, single palm plot experiments are super to plot having more number of palms. The inclusion of the concept of generalized linear models in modern statistical software makes easier in data analysis in such situation.

Though single palm plot is flexible from the technical and practical point of view for most of the field experiments in agronomy and cultural management, single palm plots are not recommended for the field experiments on coconut-based farming systems (CBFS) as such experiments are generally done at farmer's field.

Conclusion

Our previous study showed that the number of palm per plot can be reduced from six to one without changing the original design of the experiments on cultural management and fertilization of coconuts. Using the same data, this study further confirmed that coefficient of variation with single palm plot with covariate has reduced substantially compared to the other three combinations of plots (six palms plot with or without covariate or single palm without covariate). Thus it can be recommended the use of ingle palm plot with covariate as pre yield data is the most effective way to capture the unknown variability between palms in coconut experimentations. However, single palm plot size is not recommended for coconut based farming system (CBFS) trials. The methodology illustrated in this paper can easily be used to reduce the unknown variability of other tree crops, without conducting new trials.

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Appendix A

Objective and the treatments of each experiment

Experiment	Objective	Treatments
1 & 2	Substitution of inorganic nitrogen requirement of coconut palms	T_1-no fertilizer T_2-Adult Palm Mixture (APM) T_3-Gliricidia from outside + P & K T_4-Gliricidia in-situ + P & K T_5-cow dung + P & K

3 & 4	Evaluation of different fertilizer application techniques on the yield of coconut	T_1-no fertilizer but turning soil T_2-APM/turn/no mulch T_3-APM/turn/mulch T_4-Adult Coconut Mixture/Urea in dry period/turn/mulch T_5-APM in a 30cm wide, circular band, 60cm away from the palm/turn/mulch T_6-localized application of dug at 60cm distance from the palm and mulch
5	Comparison of different weed management systems and their effects on coconut yield	T_1-slashing and mulching T_2-slashing and removing the slash T_3-Glyphosate 2.88 kg /ha T_4-Glyphosate 1.44 kg /ha T_5-cover cropping T_6-unweeded
6	Study the effect of high density planted Gliricidia and Acacia under coconut for substitute of inorganic nitrogen of coconut palms	T_1-mulch with coconut fronds T_2-Gliricidia-density 1 (16 trees/coconut square) T_3-Gliricidia-density 2 (24 trees/coconut square) T_4-Gliricidia-density 2 lopping buried in ¼ circle trenches T_5-Acacia- density 1(16 trees/coconut square) T_6-Acacia- density 2(24 trees/coconut square)
7	Effect of chloride on coconut yield	T_1-control T_2-KCl – 1.6 kg/palm/year T_3-K_2SO_4 – 1.8 kg/palm/year T_4-NaCl – 1.2 kg/palm/year T_5-Na_2SO_4 – 1.45 kg/palm/year