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Use of Covariates in Improving Precision of Field Experiments in Rubber

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ABSTRACT. *An attempt was made to identify effective covariates using secondary data to improve precision in field experiments on rubber. Pre-treatment records of yield, girth, tapping panel variables such as; bark thickness, tapping cut length and tapping cut height were used to adjust post-treatment yield. Double covariance was employed to adjust rubber yields using possible combinations of pre-treatment yield, girth and tapping panel variables. Seed weight and budded stump weight were used to adjust measurements during the immature stage.*

Considerable gain in precision was obtained in analysis of post-treatment yield by using pre-treatment yield and girth as covariates. A declining behaviour was observed in the efficiency with lapse of time. Yet, the efficiency obtained through pre-treatment girth was found to be comparatively more stable. On rare occasions, double covariance analysis proved to be superior to single covariance analysis.

Adjustment by seed weight had reduced the variability in number of leaves and seedling diameter, with respective efficiencies of 34% and 84% when compared to the analysis without adjustment. An increase in efficiency of 132% and 13% was obtained for shoot length and number of leaves when budded stump weight was used as a covariate.

INTRODUCTION

The high unaccounted variability in experiments with perennial crops continues to present problems, in spite of the recent advances in the methods of field experimentation. Different ways of blocking may reduce unexplained

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variability in experiments in the presence of environmental variation. However, blocking is not regraded as an effective measure in the presence of variability inherent to individual trees. The idea of 'calibration' *viz.* the use of supplementary information, provides a satisfactory means of reducing unexplained variability. This method known as the analysis of covariance has been widely used in crop experimentation. However, Finney (1989) reported that the adjustment of means by the use of covariates is a comparatively under-exploited technique. Pearce *et al.* (1988) were of the view that the method of covariance analysis work more effectively with perennial crops.

As reported by Paardekooper (1971), covariance analysis can be successfully used in tapping and stimulation experiments in rubber where the variation inherent to the tree is substantial. However, the major disadvantage of using pre-treatment yield records in calibration is the undue delay of the experiment caused by the collection of pre-treatment records. Many researchers have stressed that the gain in precision usually outweighs the loss in time. The problem is left to the experimenter whether to continue the pre-treatment recording and weigh it against the expected gain in precision.

Presently, several variables are being measured as pre-treatment records in field experiments with rubber conducted by the Rubber Research Institute of Sri Lanka. However, no comprehensive study has yet been undertaken to evaluate the effectiveness of covariates in terms of improvement in precision of results. This paper attempts to identify effective covariates using secondary data of several field experiments. Other possibilities of minimizing the initial variability in field experimentation of rubber are also discussed.

METHODOLOGY

Field experiments on rubber can be classified according to the degree of maturity of the trees, *viz.* experiments on immature and mature plantations. Experiments with mature rubber begin when the trees come into tapping, the period varying from five to seven years from planting. In this study, several field experiments falling into immature and mature stages of rubber were analyzed to assess the benefit of covariance analysis in field experimentation.

The ratio $Vy/Vy.x$ (Cochran and Cox, 1957) was employed in evaluating the gain in precision where, Vy = Residual mean square of the unadjusted dependant variable, and $Vy.x$ = Effective residual mean square of the adjusted dependant variable calculated from;

$$Vy.x = V'y.x \{1 + \frac{Trt.MS\ for\ x}{Res.SS\ for\ x}\}$$

where, $V'y.x$ = Residual mean square of the adjusted dependant variable, y = Post-treatment variable, and x = Pre-treatment variable for single covariance analysis.

For double covariance analysis, the gain in precision was assessed by the ratio of the error variance of the unadjusted variable (Vy) to the effective error mean square of the adjusted variable ($Vy.x_1x_2$) (Steel and Torrie, 1980). $Vy.x_1x_2$ was calculated using the following equation,

$$Vy.x_1x_2 = V'y.x_1x_2 \{1 + \frac{T_{11}E_{22} - 2T_{12}E_{12} + T_{22}E_{11}}{(t-1)(E_{11}E_{22} - E_{12}^2)}\}$$

where, $V'y.x_1x_2$ = Error variance of the adjusted dependant variable, T_{11} and T_{22} = Treatment sums of squares for x_1 and x_2, T_{12} = Treatment sum of products for x_1 and x_2, E_{11} and E_{22} = Residual sums of squares for x_1 and x_2, E_{12} = Residual sum of products for x_1 and x_2 and t-1 = Degrees of freedom for treatments.

RESULTS AND DISCUSSION

Rubber yield as a pre-treatment record

Yields recorded before the commencement of the experiment are most effective as a covariate during the early years of experimentation. However, the effectiveness declines with time and depends mainly on the length of time over which the pre-treatment records were taken (Narayanan, 1966; 1968; 1970). However, there is insufficient information on the optimum length of calibrating period to obtain a reliable estimate of the inherent yield variations.

When pre-treatment yield is recorded for 6 months (Exp. No. 1, Table 1), the relative efficiency was 101% in the first year and reduced to 82% and 72% in second and third years respectively. Thereafter, the relative efficiency dropped below 0%. Pre-treatment records over 2 months also have reduced the unexplained variability to a considerable extent (Exp. No. 3 and 4, Table 1). The declining behaviour of the efficiency index with time was observed even for monthly records.

Table 1. **Efficiency of using pre-treatment rubber yield as a covariate in different experiments on *Hevea*.**

Experiment		Availability of pre-treatment records	Efficiency Index (EI) (Vy/Vy.x)	
1	Fertilizer application with conventional and soil and foliar mixtures	6 months	year 1 year 2 year 3 > 3 years	2.01 1.82 1.72 < 1
2	Effect of tapping systems on yield of PB 86	6 months	year 1 year 2 > 3 years	2.31 1.78 < 1
3	Effect of application of fungicides for bark rot on latex volume of rubber	2 months	month 1 month 2 month 3 > 4 months	4.84 3.24 2.69 < 2
4	Effect of application of fungicides for bark rot on Dry Rubber Content (DRC) of rubber	2 months	month 1 month 2 > 3 years	2.44 2.10 < 2

This study indicates that considerable gain in precision can be obtained in analysis of post-treatment yield records by using pre-treatment yield records as a covariate for the first 2-3 years of experiments. However, the declining behaviour of the efficiency was observed, when the covariate is used for long term experiments (Table 1).

In field experiments of rubber, it would not be feasible to delay the commencement of experiments too long to obtain the necessary preliminary data. However, for major fertilizer response experiments lasting 5 or more years, a delay of at least 12 months would be advisable because most fertilizer studies have ended up with no apparent yield response. Moreover, it is important to reduce the standard errors of treatment comparisons so that even small but economic responses can be detected. Perhaps, the number of replications should be higher to achieve the same degree of accuracy in the absence of pre-treatment records.

The current practice in fertilizer experiments is to obtain pre-treatment yield records for about 3 to 6 months. However, it is advisable to obtain a full year's data with 08 test tappings according to the schedule suggested by Wijesuriya and Thattil (1995) to capture the seasonal fluctuations in tree performance. It is also advisable to keep records of bulk yields of smaller blocks in research sites so that the experimenters will be able to design their experiments with previous information such as gradients in the field and tree performances.

Trunk girth as a pre-treatment record

Trunk girth is an important growth measurement in experiments with rubber even during immature stages. A considerable gain in precision can be obtained when yield records are adjusted using pre-treatment girth records. Significant relationships were found between yield and girth for various rubber clones (Narayanan and Ho Chai Yee, 1970; Wickramasinghe and Abayapala, 1980; Ong Seng Haut, 1981; Thattil *et al.*, 1991). Pre-treatment girth (if girth in experimental trees are variable) can be successfully used to reduce the initial variability in rubber yield (Table 2). The improvement in precision in the adjustment of post-treatment girth is obvious since such records are interdependant. However, when girth is less variable as observed in experiments 2 and 3 (Table 2), no significant gain in precision was observed, which is true for any pre-treatment variable.

As stated by Narayanan (1968), the effectiveness of girth as a covariate is more consistent and can be used effectively during the first three years to adjust yield. There were certain instances where pre-treatment girth could be effectively used in adjusting yield for 3 consecutive years (Exp. No. 1, Table 2). However, further evidence is needed before making firm conclusions.

Compared to other possible covariates (bark thickness, tapping cut length and tapping cut height), measurement of girth is easier and can be accurately taken. Therefore, girth records are statistically sound and practically acceptable as a covariate in adjusting rubber yields.

Double covariance analysis

The use of double covariance analysis using pre-treatment yield and girth as simultaneous calibrating variates for improving the precision of post

Table 2. Efficiency of using pre-treatment girth as a covariate in adjusting yield of different experiments on *Hevea*.

Experiment			Efficiency Index (EI) (Vy/Vy.x)
1	Fertilizer application with conventional and soil and foliar mixtures	year 1	2.31
		year 2	1.88
		year 3	1.61
		> 4 years	< 1
2	Phosphates for bush legumes	year 1	< 1
3	Optimum N, P and K levels under mulched and normal conditions	year 1	< 1
4	Effect of tapping systems on yield of PB86	year 1	1.62
		> year 2	< 1
5	Clone evaluation trial (RRIC 100, 101, 102)	year 1	1.59

-treatment yield has been assessed by Narayanan (1970) for fertilizer experiments of *Hevea*. However, no firm conclusions were made in favour of double covariance compared to single covariance analysis.

As shown in Table 3, on several occasions, double covariance proved to be superior to single covariance analysis; however, no marked differences in precision were obtained. The efficiency index based on double covariance analysis declined with time for the experiments 1 and 3, but was more consistent compared to single covariance analysis.

Although double covariance analysis will not necessarily increase further the precision of post-treatment comparisons compared to one or the other of the covariates separately, the choice of the analysis depends on the circumstances of the experiment. For instance, double covariance can be effectively used in reducing initial variability with the lapse of time. Therefore, whenever possible it is desirable to collect adequate records of all possible pre-treatment variables *viz* girth, yield and tapping panel variables before application of treatments.

Table 3. **Comparison of efficiency between double and single covariance analysis on yield in experiments with *Hevea*.**

Experiment		Double Covariance ($V_y/V_{y.x1x2}$)		Single Covariance ($V_y/V_{y.x}$)			
		Covariance	EI*	Covariate	EI	Covariate	EI
1. Fertilizer application with conventional and soil and foliar mixtures	year 1	girth/yield	1.98	girth	2.31	yield	2.01
	year 2		1.81		1.88		1.81
	year 3		1.80		1.61		1.27
2. Phosphates for bush legumes	year 1	girth/yield	1.78	girth	0.82	yield	0.74
3. Effect of tapping systems on yield of PB 86	year 1	girth/yield	1.86	girth	1.62	yield	2.31
			0.88		0.61		1.78
			0.89		0.42		0.67
4. Clone evaluation trial (RRIC 100, 101, 102)	year 1	girth/BT	1.78	girth	1.69		
	year 1	girth/TCL	1.76		1.69		
	year 1	girth/TCH	0.96		1.69		

* EI - Efficiency Index BT - Bark Thickness TCL - Tapping Cut Length
TCH - Tapping Cut Height

Seed weight and budded stump weight as pre-treatment records

Approaches such as visual selection of seedlings during the nursery stage are usually carried out to minimize the root stock variability. However, the existence of root stock variability was reported by Senanayake *et al.* (1975). Selection of uniform planting material can be practiced successfully to control the unexplained variability in experiments. Another possibility is to obtain budded stump weights and seed weights before field establishment. A considerable gain in precision was found when seed and budded stump weights were used as covariates in analyses of variance (Table 4). When seed weight is taken as the covariate the relative efficiency was 34% higher (EI=1.34) with respect to number of leaves while the efficiency was 87% (EI=1.87) with respect to seedling diameter. However, the relative efficiency was low (1%) with respect to height. Hence, seed weight and seedling diameter can be successfully used in reducing initial variability in experiments mainly confined to the immature stage of rubber.

Table 4. Use of budded Stump Weight and Seed Weight as Covariates in experiments with Hevea.

Pre-treatment	Post-treatment	Efficiency Index (EI)
Seed weight[1]	No. of leaves	1.34
Seed weight[1]	Seedling diameter	1.87
Seed weight[1]	Plant height	1.01
Budded stump weight[2]	No. of leaves	1.13
Budded stump weight[2]	Shoot length	2.32

Experiments:

[1] Substitution of top soil by sub soil mixed organic material in poly bag fillings

[2] Effect of slow release fertilizers on growth of nursery plants

Other possibilities of minimizing initial variability in fertilizer trials of rubber

Use of pre-treatment soil nutrient data in experiments with rubber have been used in characterization of soils. However, no attempt was made to adjust post-treatment soil nutrient data by pre-treatment records. Collection of pre-treatment soil data will not cause undue delays when compared to pre-treatment yield recording. Therefore, it is advisable to record pre-treatment soil nutrient values to reduce positional variability in rubber soils. One problem is the high cost of soil analysis. Block effects can also be used effectively in reducing variability in experiments with rubber especially in fertilizer experiments where the response also depends on initial soil nutrient status.

CONCLUSIONS

Pre-treatment yield is most effective as a covariate in adjusting post-treatment yield during the early years, but the efficiency declined with time. Pre-treatment girth which can be accurately and easily measured is comparatively more consistent in terms of efficiency with lapse of time. For experiments on immature rubber, measurement of seed weight and budded stump weight have reduced the initial variability to a substantial extent. No firm conclusions were made in favour of double covariance compared to single covariance analysis.

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