Girth as a Calibrating Variate for Improving Field Experiments on Hevea Brasiliensis

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The value of girth as a calibrating variate for improving the precision of post-treatment yield comparisons is illustrated by means of a few manuring experiments. It is shown that covariance analysis reduces the experimental error at least in the initial 3 to 4 years of the experimental stage. The use of both girth and yield as double covariates is suggested for major manuring experiments lasting from 5 to 10 years.

The method of calibration according to PEARCE AND TAYLOR (1950) involves the laying down of experiments on trees that have been under observation for a period of time so that their individual characteristics are known. Then the performance of trees under various treatments can be considered in relation to what might have been expected of them had no differential treatments been applied, the statistical technique used being the analysis of covariance. The measurements to be used for calibration should not themselves have been affected by the treatments. Usually girth at a particular height and yield for a period of time before the application of treatments are used. It is also implied that differences observed during the calibration period will not influence the responses to the treatments. Attention has also been drawn (NARAYANAN, 1966) to the smallness of the treatment effects which are of economic value in fertiliser trials in *Hevea* and has shown that covariance analysis on the yields recorded during the calibration period helps to increase the precision of the post-treatment yield comparisons in the first 3 years of an experiment. Several authors have studied the relationship between tree growth and yield and have considered various factors affecting this relationship. In particular, LONGWORTH AND FREEMAN (1963) recently have studied the usefulness of trunk girth as a calibrating variate for experiments on cacao and PEARCE AND BROWN (1960) on fruit trees. The present study seeks to investigate its usefulness in fertiliser trials on mature rubber.

EXPERIMENTAL

The details of the ten different experiments examined are listed in *Table 1*. For convenience, the experiments are referred to by the initial letters (A–L) given in column 1. Experiments (A–G) have already been discussed by the author (1966) in connection with the study of covariance analysis of post-treatment yield data on pre-treatment yield records. For Experiments J–L, the relevant results of the covariance analysis of post-treatment yield records on yield as a calibrating variate have also been incorporated in this study (*Table 4*).

Pre-treatment girths relate to trunk measurements on individual trees at a uniform height averaged on a *per tree* basis by plots. The post-treatment yields relate to cuplump coagulum that had been air-dried for about a month, bulked for weighing by plots and recording on a *per tree* basis.

Experiments A, B, K, L are 3^3 factorial trials in single replicates, in 3 blocks of 9 treatments each. In July 1963, the plots of experiment B were split to include magnesium at two levels. Experiments C, D, E and J are 2^5 factorial experiments in single replicates, in blocks of 8 plots each so as to confound higher-order interactions. Experiment C was laid out initially as a 2^3 MgMnCu factorial, X and Y being dummy factors. In early 1962, nitrogen and potash treatments replaced the dummy factors. Experiment F is a 2^4 NPKMg factorial in 3 replications; blocks of 8 plots being obtained by confounding the NPKMg interaction. Experiment G is a clonal cum manuring trial con-

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sisting of 3 clones, RRIM 501, PR 107 and Tjir 1, in two replications. The manuring treatments form a 3^2 CuK factorial, the 9 treatments being blocked by clones.

Dates of the pre-treatment girth records and first application of fertilisers in the different experiments are listed in *Table 1*. About 25–30 centrally located trees usually have been taken in each plot for the yield recordings but the girth measurements were made on larger numbers. In all experiments, the plots were provided with adequate 'guards' to protect them from inter-root competition. Plot size generally varied between 0.5 to 1 acre.

The ratio $Vy/Vy.x$ (COCHRAN AND COX, 1950) was used to express the change in precision resulting from using the pre-treatment measurements as a calibrating variate.

Vy is the error variance of the unadjusted yields

$Vy.x$ is the effective error mean square of the adjusted yields and is given by

$$Vy.x = V'y.x\left(1 + \frac{\text{Treatment mean squares for } x}{\text{Residual sum of squares for } x}\right) \quad \ldots (1)$$

$V'y.x$ is the error variance of the adjusted yields.

$$\text{S.E. of } b = \sqrt{\frac{V'y.x}{\text{Residual sum of squares for } x}} \quad \ldots (2)$$

b is the regression coefficient defined by $\dfrac{Cov\ xy}{Vx}$

$Cov\ xy$ is the covariance of the pre-treatment girths and post-treatment yields.

Vx is the residual variance of the pre-treatment girths.

RESULTS AND DISCUSSION

Table 2 sets out details of the changes in precision on yield data obtained by the use of girth as a calibrating variate and also the regression coefficients and their standard errors in the trials A–L that are the subjects of this investigation. The relationship observed between the pre-treatment girth and post-treatment yield is illustrated in *Figure 1* (for fourth year of experiment K). In Experiments A–D, F, J–L, increases in precision were consistently evident (the corresponding regression coefficients being significant), usually in the range 1.05 to 4.37. The pattern of the increased precision with time in these trials was not consistent but the increase usually was maintained for the first 3–4 years. On an average excluding Experiment D, the order of the increased precision ranged from about 1.2 in the first year, 1.4 in the second and third years, and 1.3 in the fourth year. In Experiments E and G, there were isolated instances of increased precision resulting from the use of girth as a calibrating variate but generally the increase was negligible.

It has already been shown (NARAYANAN, 1966) that with the use of pre-treatment yield records ranging from 2 to 8 months as a calibrating variate, the increased precision in yield resulting by the use of covariance continued for at least the first three years of the experiment. Calculations showed that the linear correlations between pre-treatment girths and pre-treatment yields (NARAYANAN, 1966) were significant at 5% level only in four of the ten experiments (*Table 3*). Though these correlations depend to a certain extent on the length of the pre-treatment yield records utilised, it is apparent that the pre-treatment girths and yields act as uncorrelated calibrating variates in some cases but not in others. Only in Experiments D and F did the pre-treatment girths account for as much as 50% of the pre-treatment yield variations.

Of the experiments which showed no significant correlations between pre-treatment yield and girth, Experiments E and G showed increased precisions when yield but not when girth was used as a calibrating variate (NARAYANAN, 1966). Experiments A and C gave increased precisions in yield by both yield and girth as calibrating variates. Experiments K and L gave increased precisions in yield using girth but not yield as a calibrating variate (*Table 4*). Of the experiments which gave significant correlations between the pre-treatment yields and pre-treatment girths, Experiments B, D and F showed increased precisions in yield by the use of both yield and girth as calibrating

TABLE 1. EXPERIMENTAL DETAILS AND PRE-TREATMENT RECORDS

Experiment	Planting distance, ft	Plot size, acre	Clone and date of planting/budding	Design	First application of fertilisers	Pre-treatment records	
						girth	yield
A	22 × 11	0.82 7 rows of 21 points	PB 86 Replanted Nov '48 Budded Jan '51	3^3 NPK factorial in single replicate—blocks of 9 treatments	May '58	May '58	Dec '57—April '58 (5 months)
B	22 × 11	1.00 9 rows of 20 points	PB 86 Planted '48 Budded Sept/Nov '49	3^3 NPK factorial in single replicate—blocks of 9 treatments	May '59	Oct '58	Oct '58—April '59 (7 months)
C	30 × 8	0.54 7 rows of 14 points	PB 86 Planted '49	2^5 MgMnCuXY factorial in single replicate—blocks of 8 treatments	Feb '60	Feb '60	Dec '59—Feb '60 (3 months)
D	22 × 11	Approx. 0.62 8 rows of 14 points	Gl 1 Planted '50 Budded '51	2^5 NPKCu and type of P factorial in single replicate—blocks of 8 treatments	Feb '60	Feb '60	Dec '59—Jan '60 (2 months)
E	16 × 16	0.49 7 rows of 12 points	PB 86 Planted '49 Budded Nov '50	2^5 NPMgCu and type of P factorial in single replicate—blocks of 8 treatments	Feb '60	Feb '60	Jan–Feb '60 (2 months)
F†	22 × 11	0.80 contour planting	RRIM 501 Planted '50 Budded '51	2^4 NPKMg factorial in 3 replications—blocks of 8 treatments	May '59	Aug '59	Sept '58—April '59 (8 months)
G	66 × 4	0.21 1 row of 35 trees	RRIM 501 PR 107 and Tjir 1 Budded Jan–March '51	3^2 CuK factorial in 2 replications for each of the 3 clones—treatments are blocked in clones	Sept '58	March '58	July—Aug '58 (2 months)
J	20 × 12	0.73 6 rows of 22 points	PB 86 Planted '49 Budded '50	2^5 PKMgMn and type of P factorial in single replicate—blocks of 8 treatments	Feb '60	Jan '60	Jan—Feb '60 (2 months)
K	15 × 15	0.47 9 rows of 10 points	PB 86 Budded stumps Planted '51	3^3 NKMg factorial in single replicate—blocks of 9 treatments	March '62	Jan '62	Jan—March '62 (3 months)
L	23 × 6¾	0.50 contour planting	Tjir 1 Planted '52 Budded '53	3^3 NMgMn factorial in single replicate—blocks of 9 treatments	Aug '61	Aug '61	August '61 (1 month)

Note: †It is assumed that the girth at August 1959 (taken here as pre-treatment) remain unaffected by the first treatment application in May 1959.

TABLE 2. ANALYSIS OF COVARIANCE OF PRE- AND POST-TREATMENT DATA

Experiment	Post-treatment data	Yield (tahils/tree/tapping)					Remarks
		1st year	2nd year	3rd year	4th year	5th year	
A	$Vy/Vy.x$ Regr. coeff. $b \pm$ S.E.	0.98 0.0010 ± 0.0006	1.22 0.0014 ± 0.0006*	1.99 0.0022 ± 0.0005***	1.11 0.0016 ± 0.0007*	1.05 0.0018 ± 0.0009 (P< 0.10)	*Vy* based on 15 d.f.
B	$Vy/Vy.x$ Regr. coeff. $b \pm$ S.E.	0.98 0.0014 ± 0.0010	1.12 0.0018 ± 0.0008 (P< 0.10)	1.38 0.0030 ± 0.0010→**	1.13 0.0019 ± 0.0009*		*Vy* based on 15 d.f.
C	$Vy/Vy.x$ Regr. coeff. $b \pm$ S.E.	1.43 0.0015 ± 0.0005**	1.13 0.0011 ± 0.0005→*	1.45 0.0025 ± 0.0008**	1.50† 0.0032 ± 0.0010**	0.85† 0.0018 ± 0.0022	*Vy* based on 22 d.f., or 13 d.f.
D	$Vy/Vy.x$ Regr. coeff. $b \pm$ S.E.	4.37 0.0040 ± 0.0005***	2.82 0.0041 ± 0.0007***				*Vy* based on 14 d.f.
E	$Vy/Vy.x$ Regr. coeff. $b \pm$ S.E.	1.12 0.0033 ± 0.0016 (P< 0.10)	0.99 0.0026 ± 0.0018	1.03 0.0018 ± 0.0011			*Vy* based on 14 d.f.
F	$Vy/Vy.x$ Regr. coeff. $b \pm$ S.E.	1.13 0.0029 ± 0.0012*	1.47 0.0047 ± 0.0012***	1.22 0.0066 ± 0.0012**			*Vy* based on 32 d.f.
G††	$Vy/Vy.x$ Regr. coeff. $b \pm$ S.E.	0.93 0.0175 ± 0.0298	0.97 0.0349 ± 0.0309	1.16 0.1050 ± 0.0433*	1.02 0.0586 ± 0.0365	0.93 0.0303 ± 0.0696	*Vy* based on 24 d.f.
J	$Vy/Vy.x$ Regr. coeff. $b \pm$ S.E.	1.41 0.0024 ± 0.0009*	1.37 0.0022 ± 0.0008*	1.27 0.0024 ± 0.0010*	1.16 0.0037 ± 0.0019 (P< 0.10)	1.19 0.0023 ± 0.0011 (P< 0.10)	*Vy* based on 14 d.f.
K	$Vy/Vy.x$ Regr. coeff. $b \pm$ S.E.	1.12 0.0024 ± 0.0012 (P< 0.10)	2.15 0.0053 ± 0.0012***	1.88 0.0057 ± 0.0014**	1.96 0.0058 ± 0.0014→***	1.15† 0.0041 ± 0.0020 (P< 0.10)	*Vy* based on 15 d.f.
L	$Vy/Vy.x$ Regr. coeff. $b \pm$ S.E.	0.96 0.0014 ± 0.0011	1.62 0.0029 ± 0.0008**	1.11 0.0033 ± 0.0017 (P< 0.10)	1.15 0.0027 ± 0.0013→*	1.91 0.0054 ± 0.0013**	*Vy* based on 15 d.f.

†Does not cover one full year ††Yield has been expressed in g/tree/tapping
$Vy.x$ denotes the effective error mean square of the adjusted yields, ***: $P< 0.001$, **: $P< 0.01$, *: $P< 0.05$, 12 tahils = 1 lb.

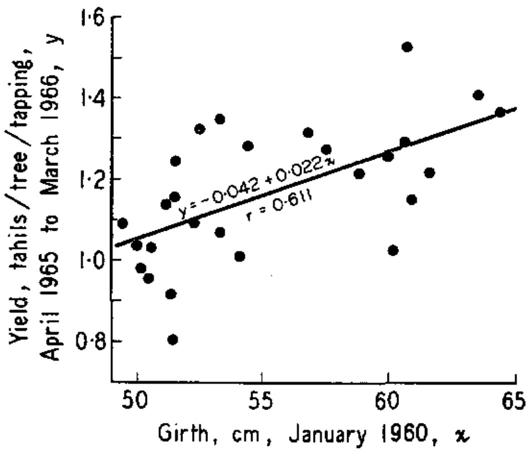

Figure 1. General relationship of individual plot means between pre-treatment girth data of January 1962 and post-treatment yield data of April 1965 to March 1966 (4th year) (Experiment K).

variates but experiment J showed increased precision in yield only when girth was used as a calibrating variate. Thus both yield and girth as calibrating variates could give appreciable gain in precision in the post-treatment yield records. Where yield and girth are inter-related, yield might be a better calibrating variate than girth and vice versa. In other circumstances yield and girth may offer as uncorrelated calibrating

TABLE 3. LINEAR CORRELATIONS BETWEEN PRE-TREATMENT YIELDS AND GIRTHS FOR THE DIFFERENT EXPERIMENTS

Experiment	n	Correlation coeff. r	
A	27	0.251	N. S.
B	27	0.429	*
C	32	0.109	N. S.
D	32	0.740	***
E	32	0.292	($P < 0.10$)
F	48	0.700	***
G	54	−0.005	N. S.
J	32	0.478	**
K	27	0.070	N. S.
L	27	−0.056	N. S.

***: $P<0.001$, **: $P<0.01$, *: $P<0.05$, N.S.: Not significant

variates. A double covariance on pre-treatment yields and girths is indicated as desirable for both or either of the two calibrating variates may be useful.

When initial yield is used as a covariate, the main draw-back is that we do not know precisely as to how long the recordings have to be made in the calibrating period for getting a reliable estimate of the yield variations. The current practice in manurial experiments is to procure pre-treatment yield records for about 3 to 6 months; a full year's data covering seasonal fluctuations in tree performance is preferable.

TABLE 4. ANALYSIS OF COVARIANCE OF PRE- AND POST-TREATMENT DATA (YIELD ON YIELD)

Experiment	Post-treatment data	Yield (tahils/tree/tapping)			Remarks
		1st year	2nd year	3rd year	
J	$Vy/Vy.x$	0.86	0.86	0.88	Vy based
	Regr. coeff. $b \pm$ S.E.	0.0022 ± 0.2456	0.0314 ± 0.2235	−0.1625 ± 0.2606	on 15 d.f.
K	$Vy/Vy.x$	1.13	0.90	0.88	Vy based
	Regr. coeff. $b \pm$ S.E.	0.6249 ± 0.2928 ($P<0.10$)	0.3923 ± 0.4442	0.3425 ± 0.5114	on 15 d.f.
L	$Vy/Vy.x$	0.92	0.96	0.90	Vy based
	Regr. coeff. $b \pm$ S.E.	0.0746 ± 0.1057	0.1033 ± 0.0996	0.0619 ± 0.1700	on 15 d.f.

CONCLUSIONS

The use of trunk girth seems to offer as a calibrating variate for increasing the precision of post-treatment yield comparisons. To increase the precisions of major manuring experiments lasting 5 to 10 years, it would be advisable to procure the records of both the yield and girth during the calibrating period to serve as double covariates. More work is needed to determine whether girth or yield (for a given period) offers the better calibrating variate for manuring experiments on rubber.

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REFERENCES

COCHRAN, W.G. AND COX, G.M. (1950) *Experimental Designs.* New York: John Wiley & Sons, Inc.

LONGWORTH, J.F. AND FREEMAN, G.H. (1963) The use of trunk girth as a calibrating variate for field experiments on cocoa trees. *J. hort. Sci.*, **38(1)**, 61.

NARAYANAN, R. (1966) Value of covariance analysis in manurial experiments on rubber. *J. Rubb. Res. Inst. Malaya*, **19**, 176.

PEARCE. S.C. AND TAYLOR, J. (1950) The purposes and design of calibration trials. *Rep. E. Malling Res. Stn, 1949*, 83.

PEARCE, S.C. AND BROWN, A.H.F. (1960) Improving fruit tree experiments by a preliminary study of the trees. *J. hort. Sci.*, **35(1)**, 56.