ANALYSIS OF EXPERIMENTS ON CROP ROTATION

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1. INTRODUCTION

Crop rotations play a very vital role in the plant husbandry. Of late, the importance of suitable crop rotations has been very well realised and a number of experiments on crop rotations have been laid out in different parts of the country. In the very nature of things, the analysis of such experiments is a little complex and presents novel features. The object of the present paper is to describe the method of analysis of experiments on crop rotations. The method is illustrated with the help of data of crop rotation experiments laid out at Agricultural Research Stations, Jalgaon (Maharashtra), Dharwar (Mysore) and Surat (Gujarat) in Kharif under rain-fed conditions.

2. DESCRIPTION OF THE EXPERIMENTS

The rotations and fertilisers included in all the experiments are given below :—

(1) Cotton manured with 5 cart-load farm yard manure per acre every year (C_m-C_m).

(2) Sorghum manured with 5 cart-load farm yard manure per acre every year (S_m-S_m).

(3) Cotton manured in atlernate years ($C-C_m$).

(4) Sorghum manured in alternate years ($S-S_m$).

(5) Cotton manured – Sorghum (C_m-S).

(6) Sorghum manured — Groundnut (S_m-GN)

(7) Cotton ,, — Groundnut (C_m-GN)

(8) Cotton	--	Groundnut	$(C-GN)$
(9) Sorghum	—	Groundnut	$(S-GN)$
(10) Cotton manured	—Sorghum-Groundnut		(C_m-S-GN)
(11) Cotton manured	—Groundnut-Sorghum		(C_m-GN-S)

The experiment was laid cut in randomised block with 22 plots each of $22' \times 18'$ net. There were 6 replicates. After two years of commencement the experiment was modified and the plots were further divided into two parts and in one of the part at random phosphorus was applied at 100 lb P_2O_5 per acre when the groundnut is grown on it. In the trial at Surat, Groundnut was replaced by pigeon pea and the experiment was modified after three years of commencement. After seven years of commencement of experiment, two extra plots for cotton-pigeonpea mixed with Sorghum rotation were added. At Dharwar, in 2 Course rotation of Cotton, sorghum, and 3 course rotation of Cotton, Sorghum and Groundnut, F.Y.M. was applied to Sorghum in place of Cotton. At Jalgaon, the data were available from 1949-50 to 1959-60, at Dharwar from 1948-49 to 1962-63 and at Surat from 1948-49 to 1960-1961. Further, the data for divided parts were recorded only for legumes at Jalgaon and Surat and for all the crops at Dharwar.

3. Methods of Analysis

In such experiments, the analysis of data consists of (*a*) analysis of total of each plot over years, (*b*) combined analysis of data for individual years to bring out the interaction component of rotations with years.

Consider the arrangements of cotton plots given in Table I as a two way classification in years and plots the number of observation is each cell is either one or zero. The model for the analysis is.

$$Z_{jk} = \mu + p_j + y_k + e_{jk}$$

where Z_{jk} be the yield of *j*th plot in *k*th year, μ is the general mean, p_j and y_k are the effect of *j*th plot and *k*th year respectively and *e* be the random error. Applying the principle of least squares, the estimate of p_j (eliminating '*y*') (Kempthorne, 1951) obtained by solving the normal equation is

$$\left(N_{j.} - \sum_k \frac{n_{jk}^2}{N_{.k}}\right)\hat{p}_j - \sum_{j \neq j'} \left(\sum_k \frac{n_{jk} n_{j'k}}{N_{.k}}\right)\hat{p}_{j'} = Q_j \qquad \ldots(1)$$

where $$Q_j = Z_{j.} - \sum_k \frac{n_{jk} Z_{.k}}{N_{.k}}$$

TABLE I

Arrangements of Cotton plots—Jalgaon

	Plots 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
−1	C_m	C_m	C	C_m	—	C_m	—	C	—	C_m	—	—	C_m	—	—	
Preliminary Years																
0	C_m	C	C_m	—	C_m	—	C_m	—	C	—	—	C_m	—	—	C_m	
1	C_m	C_m	C	C_m	—	C_m	—	C	—	—	C_m	—	—	C_m	—	Y_1
2	C_m	C	C_m	—	C_m	—	C_m	—	C	C_m	—	—	C_m	—	—	Y_2
3	C_m	C_m	C	C_m	—	C_m	—	C	—	—	—	C_m	—	—	C_m	Y_3
4	C_m	C	C_m	—	C_m	—	C_m	—	C	—	C_m	—	—	C_m	—	Y_4
Years																
5	C_m	C_m	C	C_m	—	C_m	—	C	—	C_m	—	—	C_m	—	—	Y_5
6	C_m	C	C_m	—	C_m	—	C_m	—	C	—	—	C_m	—	—	C_m	Y_6
7	C_m	C_m	C	C_m	—	C_m	—	C	—	—	C_m	—	—	C_m	—	Y_7
8	C_m	C	C_m	—	C_m	—	C_m	—	C	C_m	—	—	C_m	—	—	Y_8
9	C_m	C_m	C	C_m	—	C_m	—	C	—	—	—	C_m	—	—	C_m	Y_9
	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}	R

n_{jk} be the No. of observations in (j, k) cell

$$N_{j.} = \sum_k n_{jk},$$

$$N_{.k} = \sum_j n_{jk};$$

$$N = \sum_j \sum_k n_{jk}$$

These equations are not independant. To obtain a unique solution the conditions

$$\sum_j p_j = 0.$$

is imposed. The above equations together with the conditions can be written in matrix form as

$$\wedge P = Q$$

hence $$\hat{P} = \Lambda^{-1} Q$$

where Λ be the coefficient matrix of 'p'. The adjusted sums of squares due to plots is therefore $Q'\Lambda^{-1}Q$. The sums of squares due to 'y' (ignoring 'p') can be obtained in the usual manner.

If there are r replications the sums of squares due to plots within replicates can be split into plots and plots × replicates. s.s.

In the present case in the first instance sums of the yields of two parts in a plot were considered to study the yields in different rotations. The effect of phosphorus and its interaction with different rotations were studied by taking differences in yields of two parts in a plot and analysed in a manner as indicated above. There will be four types of comparisons and therefore four different errors. These are

Comparison	*Error*
(*a*) comparison of sum of two parts in a plot (main plot) averaged over year	Main plot error
(*b*) interaction of main plot with years	Main plot × year error
(*c*) comparison of two parts (sub plots) and interaction of main plots and sub-plots averaged over years	Sub plot error
(*d*) interaction of sub plots with year	Sub plot x year error

There will be correspondingly four components of variances *viz.*, (*a*) a part denoted as m_p which is constant over year but varies from main plot to main plot with variance σ^2_{mp} (*b*) a part denoted as m_y which varies from year to year within main plot with variance σ^2_{my} (*c*) a part denoted as s_p which is constant over year but varies from sub-plot to sub-plot within a main plot with a variance σ^2_{sp} and (*d*) a part denoted as s_y which varies from year to year within a sub-plot with a variance σ^2_{sy}.

Let $(Q'\Lambda^{-1}Q)_{rs}$ be the adjusted s.s. due to plots for rth replicate when sums of the two parts were considered and $(Q'\Lambda^{-1}Q)_{ts}$ is a similar s.s. when total of all the replicates were taken. Let $(Q'\Lambda^{-1}Q)_{rd}$ and $(Q'\Lambda^{-1}Q)_{td}$ are the corresponding s.s. when differences of the two parts were taken. Let 'p' and 'y' be the numbers of plots and years in a trial. The analysis of variance is given in table II.

TABLE II

Analysis of variance for sub-plot.

Source	*d.f.*	*s.s.*
Replicates (R)	$r-1$	
Main plots (adj) (P)	$p-1$	$\frac{1}{2}(Q'\Lambda^{-1}Q)_{ts}$
$R\times P$		
(Main plot error)	$(r-1)(p-1)$	$\frac{1}{2}[\sum_{r}(Q'\Lambda^{-1}Q)_{rs}-(Q'\Lambda^{-1}Q)t_s]$
Years (Y)	$y-1$	
$R\times Y$	$(r-1)(y-1)$	
$P\times Y$	$(N-p-y+1)$	
Main plot $\times$ year error	$(r-1)(N-p-y+1)$	
Sub-plot (S)	1	$\frac{1}{2N}\sum_{i=1}^{N} d_i^2$
$R\times S$	$r-1$	
$P\times S$ (adj.)	$p-1$	$\frac{1}{2}.(Q'\Lambda^{-1}Q)_{td}$
$R\times P\times S$		
(Sub plot errror)	$(r-1)(p-1)$	$\frac{1}{2}\sum_{r}[(Q'\Lambda^{-1}Q)_{rd}-(Q'\Lambda^{-1}Q)_{td}]$
$Y\times S$	$y-1$	
$R\times Y\times S$	$(r-1)(y-1)$	
$P\times Y\times S$	$(N-p-y+1)$	
Sub plot $\times$ year error	$(r-1)(N-p-y+1)$	

The expectation of error mean squares under null hypothesis can be obtained as suggested by Abraham and Agarwal 1967. The expressions of these expectations for Table II are

Error	*Expectation*
Main plot error	$\left(\frac{N-y}{p-1}\sigma^2_{mp}+\sigma^2_{my}\right)+\left(\frac{N-y}{p-1}\sigma^2_{sp}+\sigma^2_{sy}\right)$
Main plot × year error	$\sigma^2_{my}+\sigma^3_{sy}$
Sub plot error	$\frac{N-y}{p-1}\sigma^2_{sp}+\sigma^2_{sy}$
Sub plot × year error	σ^2_{sy}

In the above analysis d.f. corresponding to main plots (adj.) can be split into degrees of freedom for comparison of different rotations and for comparison among various main plots. The latter can be combined with main plot error. Similarly, the main plot × sub-plot (adj.) d.f. can be split into d.f. corresponding to rotation × sub-plot and the remaining d.f. can be combined with sub-plot error.

The values of N's for Table I are

$N_{1\cdot}=N_{2\cdot}=N_{3\cdot}=9$; $N_{4\cdot}=N_{6\cdot}=N_{8\cdot}=5$; $N_{5\cdot}=N_{7\cdot}=N_{9\cdot}=4$

$N_{10\cdot}=N_{11\cdot}=N_{12\cdot}=N_{13\cdot}=N_{14\cdot}=N_{15\cdot}=3$; $N_{\cdot k}=8,\ k=1,\ldots,9$

$Z_{j\cdot}=P_j,\ j=1,\ldots,15$; $Z_{\cdot k}=Y_k,\ k=1,\ldots,9$

Substituting the above values in (1) the normal equations together with conditions $\Sigma p_j=0$ are as follows :

where $Y_{(j)}$ is the total of Y's for the year in which j carries C. The estimates of p's can be obtained by inverting the coefficient matrix and multiplying the inverted matrix by Q matrix given on right hand side of above equations.

LONG TERM TRENDS

Trends in the yield values produced by repeated growing of crop on the same plot are also of considerable interest in these experiments. The estimates of changes in yield can be obtained by calculating linear regressions of crop yields in a rotation on time and is given by

$$b=\frac{\Sigma t_i y_i-\bar{t}\,\Sigma y_i}{\Sigma t_i^2-n\,\bar{t}^2}$$

where 'b' be the regression coefficient, t_i and y_i are the ith year and the yield in ith year respectively ; $\bar{t}$ is the mean of t and n is the

$$\begin{bmatrix}
63 & -9 & -9 & -4 & -5 & -4 & -5 & -4 & -5 & -3 & -3 & -3 & -3 & -3 & -3 & 1 \\
-9 & 63 & -9 & -4 & -5 & -4 & -5 & -4 & -5 & -3 & -3 & -3 & -3 & -3 & -3 & 1 \\
-9 & -9 & 63 & -4 & -5 & -4 & -5 & -4 & -5 & -3 & -3 & -3 & -3 & -3 & -3 & 1 \\
-4 & -4 & -4 & 28 & 0 & -4 & 0 & -4 & 0 & -1 & -2 & -1 & -1 & -2 & -1 & 1 \\
-5 & -5 & -5 & 0 & 65 & 0 & -5 & 0 & -5 & -2 & -1 & -2 & -2 & -1 & -2 & 1 \\
-4 & -4 & -4 & -4 & 0 & 28 & 0 & -4 & 0 & -1 & -2 & -1 & -1 & -2 & -1 & 1 \\
-5 & -5 & -5 & 0 & -5 & 0 & 65 & 0 & -5 & -2 & -1 & -2 & -2 & -1 & -2 & 1 \\
-4 & -4 & -4 & -4 & 0 & -4 & 0 & 28 & 0 & -1 & -2 & -1 & -1 & -2 & -1 & 1 \\
-5 & -5 & -5 & 0 & -5 & 0 & -5 & 0 & 35 & -2 & -1 & -2 & -2 & -1 & -2 & 1 \\
-3 & -3 & -3 & -1 & -2 & -1 & -2 & -1 & -2 & 21 & 0 & 0 & -3 & 0 & 0 & 1 \\
-3 & -3 & -3 & -2 & -1 & -2 & -1 & -2 & -1 & 0 & 21 & 0 & 0 & -3 & 0 & 1 \\
-3 & -3 & -3 & -1 & -2 & -1 & -2 & -1 & -2 & 0 & 0 & 21 & 0 & 0 & -3 & 1 \\
-3 & -3 & -3 & -1 & -2 & -1 & -2 & -1 & -2 & -3 & 0 & 0 & 21 & 0 & 0 & 1 \\
-3 & -3 & -3 & -2 & -1 & -2 & -1 & -2 & -1 & 0 & -3 & 0 & 0 & 21 & 0 & 1 \\
-3 & -3 & -3 & -1 & -2 & -1 & -2 & -1 & -2 & 0 & 0 & -3 & 0 & 0 & 21 & 1 \\
1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0
\end{bmatrix}
\begin{bmatrix} p_1 \\ p_2 \\ p_3 \\ p_4 \\ p_5 \\ p_6 \\ p_7 \\ p_8 \\ p_9 \\ p_{10} \\ p_{11} \\ p_{12} \\ p_{13} \\ p_{14} \\ p_{15} \\ z \end{bmatrix}
=
\begin{bmatrix} 8P_1 - R \\ 8P_2 - R \\ 8P_3 - R \\ 8P_4 - Y_{(4)} \\ 8P_5 - Y_{(5)} \\ 8P_6 - Y_{(6)} \\ 8P_7 - Y_{(7)} \\ 8P_8 - Y_{(8)} \\ 8P_9 - Y_{(9)} \\ 8P_{10} - Y_{(10)} \\ 8P_{11} - Y_{(11)} \\ 8P_{12} - Y_{(12)} \\ 8P_{13} - Y_{(13)} \\ 8P_{14} - Y_{(14)} \\ 8P_{15} - Y_{(15)} \\ 0 \end{bmatrix}$$

number of year in the experiment. The variance of 'b' is (Appendix I)

$$V(b)=\frac{12}{n(n^2-1)}\left[\frac{12}{n(n^2-1)}\left\{\sum_i\left(S(p_i)-\frac{n+1}{2}T\,(p_i)\right)^2\right\}\sigma p^2+\sigma^2_e\right]$$

where $S\,(p_i)$ and $T\,(p_i)$ are the numerical sum and total number of time variates on ith plot respectively.

4. Economics

A rotation which brings forth the maximum profit to a cultivator is considered the best rotation. The economics of various rotations can be calculated for the estimated yields obtained by following them at various ranges of prices, If $\bar{y}_i$, $\bar{p}_i$ and C_i be the estimated yield, harvest price per unit and cost of cultivation per unit for ith crop in the rotation and let C_m be the cost of manuring per unit. Let K be the cycle of the rotation. The net profit per year will be

$$\frac{1}{K}[\Sigma(\bar{p}_i\,\bar{y}_i-C_i)]-C_m$$

with a $s.e.$ of

$$\frac{1}{K}\,[\Sigma\bar{p}_i^2V(\bar{y}_i)]^{\frac{1}{2}}$$

where $V(\bar{y}_i)$ be the variance of mean yield for ith crop in a rotation.

5. Results.

5.1. *Yields.* Appendix II gives the analysis of variance for all the crops in the rotations. The sums of squares due to main plots are split into sums of squares due to rotations and rest *viz.* s.s. due to comparison of various plots. The latter were combined with main plot error (R$\times$P). Similarly, sums of squares due to main plot $\times$ sub plot interaction are split and combined with sub-plot error. The estimates of various components of variances are obtained from the errors so formed. In such cases the mean squares due to rotations are compared against theortical mean squares obtained from expected values (Table III) with appropriate degrees of freedom n_r (Cochran, 1951).

Yields of cotton and sorghum in different rotations were differing significantly. However, the yield of pigeon pea (legume) at Surat in different rotations were also significant.

TABLE III. *Analysis of variance (splitting of s. s. due to main plots and its interaction with sub-plots)*

Place	*Source*	*d. f.*	*m. s. s.*	*Thea. m. s. s.*	*F.*	n_e	*Exy. m. s. s.*
	Cotton						
JALGAON	Rotation (Rt.)	6	175·68	3·09	56·8**	57·4	$5{\cdot}30\ \sigma^2_p + \sigma^2_e$
	Main plot error	78	3·02	—	—	—	$4{\cdot}44\ \sigma^2_p + \sigma^2_e$
	Sorghum						
	Rotation (Rt.)	6	376·26	30·10	12·5**	67·1	$5{\cdot}30\ \sigma^2_p + \sigma^2_e$
	Main plot error	78	27·12	—	—	—	$4{\cdot}44\ \sigma^2_p + \sigma^2_e$
	Groundnut						
	Ratation (Rt.)	5	8·56	8·70	—	16·6	$4{\cdot}04\ \sigma^2_p + \sigma^2_e$
	Main plot error	73	4·60	—	—	—	$3{\cdot}45\ \sigma^2_p + \sigma^2_e$
	Rt. × Sub-plot	5	1·37	2·06	—	—	$4{\cdot}04\ \sigma^2_{sp} + \sigma^2_{sy}$
	Sub-plot error	73	1·94	—	—	—	$3{\cdot}45\ \sigma^2_{sp} + \sigma^2_{sy}$

TABLE III. *(contd.)*

Place	*Source*	*d. f.*	*m. s. s.*	*Thea. m. s. s.*	*F.*	n_e	*Exp. m. s. s.*
	Cotton						
SURAT	Rotation (Rt.)	7	220·40	8·31	26·5**	83·5	4·82 $\sigma^2_p + \sigma^2_e$
	Main plot error	89	7·27	—	—	—	4·09 $\sigma^2_p + \sigma^2_e$
	Sorghum						
	Rotation (Rt.)	7	312·42	12·80	24.4**	71·0	4·82 $\sigma^2_p + \sigma^2_e$
	Main plot error	89	12·14	—	—	—	4·09 $\sigma^2_p + \sigma^2_e$
	Pigeon pea						
	Rotation (Rt.)	5	11·56	1·70	6·8**	60·2	4.04 $\sigma^2_p + \sigma^2_e$
	Main plot error	73	1·18	—	—	—	3·45 $\sigma^2_p + \sigma^2_e$
	Rt. × Sub-plot	5	0·76	0·46	1·6	12·2	4·04 $\sigma^2_{sp} + \sigma^2_{sy}$
	Sub plot error	73	0·10	—	—	—	3·45 $\sigma^2_{sp} + \sigma^2_{sy}$

TABLE III. *(conid.)*

Place	*Source*	*d. f.*	*m. s. s.*	*Theo. m. s. s.*	*F.*	n_e	*Exp. m. s. s.*
	Cotton						
DHARWAR	Rotation (Rt.)	6	55·21	33·02	1·7	60·9	$6{\cdot}49\ \sigma^2_p + \sigma^2_e$
	Main plot error	64	22·82	—	—	—	$5{\cdot}41\ \sigma^2_p + \sigma^2_e$
	Rt. × Sub-plot	6	16·63	30·21	—	61·0	$6{\cdot}49\ \sigma^2_{sp} + \sigma^2_{sy}$
	Sub-plot error	64	19·47	—	—	—	$5{\cdot}41\ \sigma^2_{sp} + \sigma^2_{sy}$
	Sorghum						
	Rotation (Rt.)	6	882·39	107·01	8·2**	63·1	$6{\cdot}49\ \sigma^2_p + \sigma^2_e$
	Main plot error	64	106·74	—	—	—	$5{\cdot}41\ \sigma^2_p + \sigma^2_e$
	Rt. × Sub-plot	6	1·56	13·45	—	59·6	$6{\cdot}49\ \sigma^2_{sp} + \sigma^2_{sy}$
	Sub-plot error	64	8·54	—	—	—	$5{\cdot}41\ \sigma^2_{sp} + \sigma^2_{sy}$
	Groundnut						
	Rotation (Rt.)	5	127·61	112·87	1·1	54·5	$4{\cdot}94\ \sigma^2_p + \sigma^2_e$
	Main plot error	60	44·64	—	—	—	$4{\cdot}17\ \sigma^2_p + \sigma^2_e$
	Rt. × Sub-plot	5	2·84	3·95	—	49·9	$4{\cdot}94\ \sigma^2_{sp} + \sigma^2_{sy}$
	Sub-plot error	60	4·01	—	—	—	$4{\cdot}17\ \sigma^2_{sp} + \sigma^2_{sy}$

TABLE IV

Mean yield and S.E.'s in kg/ha.

Crop Rotation	*Jalgaon (Kharif) Maharashtra*			*Dharwar (Kharif) Mysore*			*Surat (Kharif) Gujarat*		
	Cotton	*Sorghum*	*Groundnut*	*Cotton*	*Sorghum*	*Groundnut*	*Cotton*	*Sorghum*	*Pigeon Pea*
$C_m—C_m$	447·65 (15·62)	— —	— —	455·27 (68·52)	— —	— —	373·40 (24·77)	— —	— —
$C—C_m$	440·77 (11·50)	— —	— —	425·96 (48·46)	— —	— —	348·59 (35·03)	— —	— —
$S_m—S_m$	— —	1145·84 (48·29)	— —	— —	1301·70 (127·45)	— —	— —	534·61 (26·96)	— —
$S_m—S$	— —	1015·59 (34·86)	— —	— —	1036·82 (90·13)	— —	— —	467·51 (38·31)	— —
$C_m—S$	452·02 (14·58)	1138·20 (38·73)	— —	629·74 (50·46)	1234·54 (91·46)	— —	475·02 (18·44)	567·95 (23·48)	— —
C—GN	603·71 (14·58)	— —	759·98 (25·88)	499·19 (50·46)	— —	1365·66 (92·17)	501·51 (18·44)	— —	279·76 (18·27)

Crop Rotation	*Jalgaon (Kharif) Maharashtra*			*Dharwar (Kharif) Mysore*			*Surat (Kharif) Gujarat*		
	Cotton	*Sorghum*	*Groundnut*	*Cotton*	*Sorghum*	*Groundnut*	*Cotton*	*Sorghum*	*Pigeon Pea*
C_m—G. N.	673·16 (14·58)	—	769·74 (25·88)	552·05 (50·46)	—	1381·46 (92·17)	538·96 (18·44)	—	309·14 (18·27)
S–G–N	—	1354·43 (38·73)	722·42 (25·88)	—	1481·68 (91·46)	1355·56 (92·17)	—	641·44 (23·48)	324·07 (18·27)
S_m –GN	—	1353·76 (38·73)	820·25 (25·88)	—	1708·06 (91·46)	1378·88 (92·17)	—	736·42 (23·48)	338·38 (18·27)
C_m -S—GN	651·15 (14·20)	1130·53 (34·77)	790·64 (22·30)	617·09 (42·44)	1425·06 (75·76)	1517·57 (79·94)	579·64 (15·79)	552·73 (22·20)	366·89 (15·62)
C_m—GN—S	455·87 (14·20)	1237·39 (34·77)	801·07 (22·35)	478·96 (42·44)	1974·71 (75·76)	1682·02 (79·94)	516·15 (15·79)	719·14 (22·20)	338·13 (15·62)
C—SPP	—	—	—	—	—	—	332·08 (19·49)	398·45 (27·68)	94·08 (19·27)

*At Dharwar in 2 course rotations of cotton, Sorghum and 3 course rotation of Cotton, Sorghum, Groundnut F.Y.M. was applied to sorghum in place of cotton.

**At Surat, groundnut was replaced by pigeon Pea.

Fig. in ( ) are the S.E.

Table IV gives the mean yields and S. E.'s in kg/ha for various crops. Yield of cotton after legume crop was significantly highest in two and three course rotations. Application of F.Y.M. to cotton in two course rotation increased its yield at all the centres though the increase was significant at Jalgaon only. For Sorghum similar results were obtained excepting that application of F.Y.M. to it gave significant increase in yield at Dharwar only.

5.2. *Effect of pnosphorus applied to legume crops*

Table V gives the mean responses to phosphorus applied on legume crops with their S. E.'s in kg/ha.

TABLE V

Rotation followed	*Jalgaon*		*Dharwar*		*Surat*	
	Response	*S.E.*	*Response*	*S.E.*	*Response*	*S.E.*
C—GN	2·24	24·66	175·77	64·99	—1·65	11·99
C_m—GN	20·00	24·66	82·66	64·99	1·82	11·99
S—GN	13·17	24·66	177·76	64·99	3·38	11·99
S_m—GN	8·93	24·66	99·89	64·99	—5·77	11·99
C_m—S—GN	77·42	22·19	170·93	55·20	48·55	10·19
C_m—GN—S	44·06	22·19	135·59	55·20	—25·02	10·19

The magnitude of response to phosphorus on legume crops is significant when it was included between cotton and sorghum rotation. It is to be noted that the residual effect of F Y.M. applied to sorghum and direct effect of phosphorus on legume crops interact negatively and gives lower response of legume crops.

In Dharwar experiment the yield of split plots was available for all the three crops. Therefore, the residual effects of phosphorus applied to legume crops were studied on the subsequent crops and are given in table VI.

TABLE VI

Residual response to phosphorus on cotton and sorghum with their S.E.'s in kg/ha—Dharwar.

Ratation followed	*Cotton*		*Sorghum*	
	Response	*S.E.*	*Response*	*S.E.*
*CR—GN	49.92	96.55	130.62	63.82
CR_m—GN	71.16	96.55	32.70	63.82
C_m—S—GN	36.58	81.81	30.18	55.19
C_m—GN—S	3.14	81.81	41.83	55.19

*CR indicates either cotton or sorghum.

Phosphorus applied to groundnut gave residual effects on cotton and sorghum, the magnitude of responses were not significant.

Fertility

Table VII gives the regression coefficients and their S.E.'s in kg/ha for various crops. In case of cotton there was deterioration in continuous cotton and cotton-groundnut rotation, the magnitude of decrease was significant at Jalgaon. In case of sorghum there was significant increase in yield rate for continuous sorghum rotations at Surat and Jalgaon were as for other sorghum rotation there was significant appreciation at Jalgaon and deterioration at Dharwar. For groundnut, at Jalgaon and Dharwar there was deterioration in fertility whereas for pigeon pea at Surat there was significant appreciation in all the rotations excepting in cotton-sorghum mixed with pigeon pea rotation.

5.3. Economics

The figures for cost of cultivation and cost of manuring with F.Y.M. used in the present study were worked out by Panse and Bokil (1964). The cost of cultivation for pigeon pea was not available, this was taken equal to that of sorghum. The cost of 40 lb. P_2O_5 at the rate of Rs. 250 per metric tonne was taken as Rs. 28.35 per ha. The current harvest prices of crops were taken from "Agriculture Situation in India, August, 1965."

TABLE VII *Regression coefficients and their S.E.'s in kg/ha.*

Crop Rotations	*Jalgaon (Kh.) Maharashtra*			*Dharwar (Kh.) Mysore*			*Surat (Kh.) Gujarat*		
	Cotton	*Sorghum*	*Groundnut*	*Cotton*	*Sorghum*	*Groundnut*	*Cotton*	*Sorghum*	*Pigeon-Pea*
C_m—C_m	—18.21 (5·29)	— —	— —	—31·07 (4·75)	— —	— —	—9·28 (2·87)	— —	— —
C—C_m	—19·70 (3·78)	— —	— —	—31·07 (3·83)	— —	— —	—10·40 (2·15)	— —	— —
S_m—S_m	— —	64 88 (11·07)	— —	— —	—72·98 (4·72)	— —	— —	16 34 (6·69)	— —
S_m—S	— —	54·45 (7 80)	— —	— —	—65·10 (3·58)	— —	— —	19·85 (4·78)	— —
G_m—S	21·58 (5·29)	83·86 (11·07)	— —	—67·56 (4·98)	—102·33 (4·90)	— —	—12·89 (2·87)	4·64 (6·69)	— —
C—GN	—23·76 (5·29)	— —	—17·19 (5·03)	—38·24 (4·98)	— —	21·70 (11·50)	—9·82 (2·87)	— —	9·21 (2·63)
C_m—GN	—14·49 (5 29)	— —	—11·59 (5·03)	—31·93 (4·98)	— —	—4·44 (11·50)	—4·21 (2·87)	— —	14·61 (2·63)
S—GN	— —	62·32 (11·07)	—20·46 (5·03)	— —	—118 60 (4·90)	—4·93 (11·50)	— —	—19·00 (6·69)	9·14 (2·63)
S_m—GN	— —	115·75 (11·07)	—28·10 (5·03)	— —	—109·48 (4·90)	—5·54 (11·50)	— —	4·88 (6·69)	13·19 (2·63)
C_m—S—GN	— 0·85 (5·26)	57·55 (11·58)	—20·04 (5·54)	—47·22 (4·85)	—128·84 (4·79)	—12·33 (11·44)	6·16 (2·84)	8·28 (6·68)	10·76 (2·61)
C_m—GN—S	7·74 (5·26)	63·25 (11·58)	—14·57 (5·54)	—27·96 (4·85)	—145·72 (4·79)	—12·33 (11·44)	1·09 (2·84)	—8·56 (6·68)	9·11 (2·61)
C—SPP	— —	— —	— —	— —	— —	— —	—3·93 (5·49)	—61·03 (13·13)	—0·99 (5·25)

Figures in ( ) are the S.E.

Table VIII gives the economics of rotations conducted at Jalgaon, Dharwar and Surat. The maximum profit was obtained in two course rotation of cotton or sorghum followed by groundnut or pigeon pea. Application of F.Y.M. to cotton or sorghum increased the profit, but the increase was not significant. The profit obtained for three course rotation stood second. It may be mentioned that at Surat the common prevalent rotation of cottonsorghum mixed with pigeon pea gave significantly low profits.

6. Summary

The analysis of experiments on crop rotation involves a number of steps. In this paper, the details of analysis of such experiments have been presented with the help of data on crop rotation experiments with cotton, sorghum and a legume crop (groundnut or pigeon pea). In these experiments failure of crops in some year or incomplete cycle of rotations disturbed the symmetry in the experiments. The methods of 'fitting constants' were applied considering the data as two way classification in plots and years. Since phosphorus was applied to legume crop in split plot, its direct effect on legume and residuals on cotton and sorghum were also examined.

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TABLE VIII—*Economics of rotations--Jalgaon (J), Dharwar (D), Surat (S)*

Harvest prices (Rs./Q)—Cotton 120·15), Sorghum (45·00), Groundnut (123·30), Pigeon pea (46·20) cost. of cultivation (Rs./ha.) Cotton (216·12), Sorghum (169·59) Groundnut (191.26) Pigeon pea (169·52)

Rotation		*Mean yieid (Q)/ha*			*Area under Crop.*			*Cost of cultivation and of Manuring (Rs./ha)*	*Gross income with current price ratio C : S : GN : PP : : 2·67 : 1·00 : 2·74 : 1·67 (Rs./ha)*	*Net Profit (Rs./ha*	*S E. (Rs./ha)*	*Gross income with price ratio C : S : GN : PP : : 3·00 : 1·00 : 3·41 : 3·41 (Rs./ha)*	*Net profit (Rs./ha)*	*S.E. (Rs./ha)*	*Gross income with price ratio C : S : GN : PP : : 4·00 : 1·00 : 2·00 : 2·00 (Rs./ha)*	*Net profit (Rs./ha)*	*S.E. (Rs./ha)*
		Cotton	*Sorghum*	*Gnut*	*Cotton*	*Sorghum*	*Gnut*										
$C_m - C_m$	(J)	4·48	—	—	1	—	—	253·29	538·27	284·98	19·35	604·80	351·51	21·40	806·40	553·11	28·06
	(D)	4·55	—	—	1	—	—	253·29	546·00	292·71	82·22	614·25	360·96	92·46	819·00	565·71	84·50
	(S)	3·73	—	—	1	—	—	253·29	448·16	194·87	29·70	503·55	250·26	33·50	671·40	418·11	44·64
$C_m - C$	(J)	4·41	—	—	1	—	—	234·76	538·27	305·51	19·35	595·35	360 59	21·04	793·80	559·04	28·06
	(D)	4·26	—	—	1	—	—	234·76	511·20	276·44	82·22	575·10	340·34	92·46	765·80	532 04	84·50
	(S)	3·49	—	—	1	—	—	334·76	419·32	184·56	42 30	471·15	136·40	47·25	628·20	393·44	63·00
$S_m - S_m$	(J)	—	11·46	—	—	1	—	206·59	495·45	288·86	22·60	495·45	288·86	21·60	495·45	288·86	21·60
	(D)	—	13·02	—	—	1	—	206·59	585·90	379·31	57·15	585·90	379·31	57·15	585·90	379 31	57·15
	(S)	—	5·35	—	—	1	—	206 59	240·75	34·16	12·15	240·75	34·16	12·15	240·75	34·16	12·15
$S_m - S$	(J)	—	10·16	—	—	1	—	188·06	436·95	246·89	21·60	436·95	248·89	21·60	436·95	248·89	21·60
	(D)	—	10 37	—	—	1	—	188·06	466·65	278·59	57·15	466 65	278·59	57·15	466·65	278·59	57·15
	(S)	—	4·68	—	—	1	—	188·06	210·60	22·54	17·10	210·60	22·54	17·10	210·60	22·54	17·10
$C_m - S$	(J)	4·52	11·38	—	½	½	—	211·41	527·59	316·18	12·60	561·15	349·74	13·15	662·85	451·44	15 76
	(D)	6 30	12·34	—	½	½	—	211·40	655·65	444·24	45·90	702·90	491·50	39·80	844·65	633·25	66·16
	(S)	4·75	5·68	—	½	½	—	211·41	413·15	201·74	12·15	448·82	237·01	13·48	555·30	343·89	17·55

Rotation		Mean yield (Q)/ha			Area under Crop.			Cost of cultivation and of Manuring (Rs./ha)	Gross income with current price ratio C : S : GN : PP :: 2·67 : 1·00 : 2·74 : 1·67 (Rs./ha)	Net Profit (Rs./ha)	S.E. (Rs./ha)	Gross income with price ratio C : S : GN : PP :: 3·00 : 1·00 : 3·41 : 3·41 (Rs./ha)	Net Profit (Rs./ha)	S.E. (Rs./ea)	Gross income with price ratio C : S : GN : PP :: 4·00 : 1·00 2·00 : 2·00 (Rs./ha)	Net Profit (Rs./ha)	S.E. (Rs./ha)
		Cotton	Sorghum	Gnut	Cotton	Sorghum	Gnut										
C−GN	(J)	6·04	—	7·58	½	—	½	203·74	828·96	625·22	18·45	989·28	785·54	22·20	884·70	680·96	17·55
	(D)	4·99	—	13·66	½	—	½	203·74	1139·49	935·75	64·26	1384·89	1181·15	78·52	1063·80	860·06	61·50
	(S)	5·02	—	2·75	½	—	½	192·87	466·78	273·98	13·05	549·84	356 97	18·72	575·55	382 68	18·48
C_m−GN	()	6 73	—	7·68	½	—	½	222·28	877·78	655·50	18·45	1043·52	821·24	22·20	951·30	729·02	17·55
	(D)	5·52	—	13·82	½	—	½	222·28	1181·13	958·83	64·26	1432·94	1210·66	78·52	1118·70	896·42	61·50
	(S)	5 39	—	3·09	½	—	½	211·41	439 91	228·50	13·05	600·91	223·29	18·72	624·15	412·74	18·48
−GN	(J)	—	13·54	7·22	—	½	⅓	180·39	749·76	569·37	18·45	858 60	678·21	21·70	629 55	449·16	14·55
	(D)	—	14·82	13·30	—	½	½	180·39	1155·09	974·70	52·03	1353·89	1173·50	73·68	934·65	754·26	39·81
	(S)	—	6·41	3·24	—	½	½	169 52	265·97	96·45	8·55	392·11	225·29	15·00	290 02	120·50	9 80
S_m−GN	(J)	—	13·54	8·20	—	½	½	198·93	810·18	611·25	18·45	933·80	734·87	21·70	673·65	474·72	14·55
	(D)	—	17 08	13·79	—	½	½	198·93	1232·38	1033·45	52·03	1442·33	1243·30	73·68	1004·85	805·92	39·81
	(S)	—	7·36	3·38	—	½	½	188 06	292·50	104·44	8·55	424·93	236·87	15·00	317·70	129·64	9·80
C_m−S− GN	(J)	6·51	11·31	9·91	⅓	⅓	⅓	204·69	755·48	550·79	11·70	867·20	662·51	14·12	797·55	592·86	12·06
	(D)	6·17	14 25	15·18	⅓	⅓	⅓	204·69	1082·93	878 34	38·54	1267·86	1063·17	46·49	1039·35	834·66	36·59
	(S)	5 80	5·53	3·67	⅓	⅓	⅓	197·45	407·18	209·73	8·10	531·67	334·22	11·20	541·05	343·60	11·10
C_m−GN−S	(J)	4·56	12·37	8·01	⅓	⅓	⅓	210·87	697·39	486·52	11·70	800·46	589·59	14·12	699·45	494·76	12·06
	(D)	4·79	19·75	16·82	⅓	⅓	⅓	204·69	1177·47	972·78	38·54	1372·14	1167·45	46·49	1088 25	883·56	36·59
	(S)	5·16	7·19	3·38	⅓	⅓	⅓	197·45	399 18	201·73	8·10	512·94	315·49	11·20	518·85	321·40	11·10
C−SPP	(S)	3·32	3·89	0·94	½	½	½	192·87	324·32	131·45	15·30	385·77	192·90	20·76	430·65	237·78	20.59

APPENDIX I

S.E. of regression coefficient.

The regression coefficient 'b' of time (t) on yield (y) is

$$b=(\Sigma ty-\bar{t}\,\Sigma y)/(\Sigma t^2-n\,\bar{t}^2)$$

The variance of 'b' is

$$V(b)=\frac{1}{(\Sigma t^2-n\,\bar{t}^2)^2}\,[V(\Sigma ty)+\bar{t}^2\,V(\Sigma y)-2\bar{t}\,\text{Cov}\,(\Sigma ty,\ \Sigma y)].$$

Let $S_n(p_i)$ and $T_n(p_i)$ be sum and number of time variable on ith plot and n be the total number of time variable in a rotation. Replacing yield by error specification, *viz.*, $y=p+e$ we have

$$V(\Sigma ty)=V[\sum_i S_n(p_i)\,.\,p_i+\sum_i t_i\epsilon_i]$$

$$=\sigma_p^2\sum_i S_n^2\,(p_i)+\sigma_e^2\,\Sigma t^2$$

$$V(\Sigma y)=V[\sum_i T_n(p_i)\,.\,p_i+\sum_i \epsilon_i]$$

$$=\sigma_p^2\sum_i T_n^2\,(p_i)+n\sigma_e^2$$

$$\text{Cov}\,(\Sigma ty,\ \Sigma y)=\text{Cov}\,[\{\Sigma S_n(p_i)\,.\,p_i+\Sigma t_i\epsilon_i\}\{\Sigma T_n(p_i)\,.\,p_i+\Sigma\epsilon_i\}]$$

$$=\sigma_p^2\sum_i S_n(p_i)\,.\,T_n(p_i)+n\,\bar{t}\,.\,\sigma_e^2$$

(a) If 't's has common difference unity, then

$$\Sigma t^2-n\,\bar{t}^2=\frac{n(n^2-1)}{12}$$

and $$V(b)=\frac{12}{n(n^2-1)}\left[\frac{12}{n(n^2-1)}\left\{\sum_i\left(S_n(p_i)-\frac{n+1}{2}\,T_n(p_i)\right)^2\right\}\sigma_p^2+\sigma_e^2\right].$$

If there are 'r' replicates then,

$$V(b)=\frac{12}{r.n(n^2-1)}\left[\frac{12}{n(n^2-1)}\left\{\sum_i\left(S_n(p_i)-\frac{n+1}{2}\,T_n(p_i)\right)^2\right\}\sigma_p^2+\sigma_e^2\right]$$

(b) If 't's does not have common difference, then

$$V(b)=\frac{1}{r.(\Sigma t^2-n\,\bar{t}^2)}\left[\frac{1}{(\Sigma t^2-n\,\bar{t}^2)}\left\{\Sigma\left(S_n(p_i)-\bar{t}\,T_n(p_i)\right)^2\right\}\sigma_p^2+\sigma_e^2\right]$$

APPENDIX II

Analysis of variance in (lb/plot)² for Cotton and Sorghum

Place	Source	d. f.	Cotton		Sorghum		Exp. m.s.s
			m.s.s.	F	m.s.s.	F	
JALGAON	Replicates (R)	5	9·16	3·42**	145·00	10·39**	
	Main plots (P)	14	78·68	29·36**	242·52	17·37**	
	R×P	70	2·68		13·96		
	(Main plot error)						4·5 $\sigma_p^2+\sigma_e^2$
	Years (Y)	8	736 16	287·56**	1955·74	164·90**	
	R×Y	40	7·08	2·77**	36·64	3·09**	
	P×Y	49	11·08	4·33**	108·80	9·17**	
	Main plot×year error	245	2·56		11·86		σ_e^2
SURAT	Replicates (R)	5	20 94	3·74**	23·31	1·99	
	Main plots (P)	16	108·91	19·48**	145·80	12·48**	
	R×P	80	5·59		11·68		5·25 $\sigma_p^2+\sigma_e^2$
	(Main plot error)						
	Years (Y)	10	726·80	484·53**	342·50	40·68**	
	R×Y	50	6·40	4·27**	23·78	2·82**	
	P×Y	68	11·32	7·55**	23·50	2·74**	
	Main plot× Year error	340	1·50		8·42		σ_e^2

Place	Source	d.f.	Cotton		Sorghum		Exp. m.s.s.
			m.s.s.	F	m.s.s.	F	
	Replicates (R)	4	4·58	—	28·62	2·17	
	Main plots (P)	14	33·67	2·22**	406·75	30·91**	
	R×P	56	15·16		13·16		5·50 $\sigma_p^2+\sigma_e^2$
	(Main plot error)						
D	Years (Y)	10	167·63	31·99**	1425·18	276 73**	
	R×Y	40	9·29	1·77**	7·31	1·42**	
H	P×Y	63	6·60	1·26**	25·04	4·86**	
A	Main plot×rear error	252	5·24		5·15		σ_e^2
R	Sub-plot (S)	1	2·80	—	22·10	3·68	
	R×S	4	13·10	—	1·22	—	
W							
	P×S	14	17·09	1·10	6·01	—	
A	R×P×S	56	15·49		6·92		5·50 $\sigma_{sp}^2+\sigma_{sy}^2$
R	(Sub plot error)						
	Y×S	10	5·71	1·21	2·63	—	
	R×Y×S	40	5·46	1·16	4·31	1·43	
	P×Y×S	63	4·28	—	2·74	—	
	Sub plot×year error	252	4·71		3·10		σ_{sy}^2

**Significant at 1%

*Significant at 5%

Contd. II

Analysis of variance in (lb/plot)^2 for legume crops

Source	d. f.	Jalgaon Groundunt		Surat Pigeon-pea		Est. m.s.s.	d. f.	Dharwar Groundnut		Est. m.s.s.
		m.s.s.	F	m.s.s.	F			m.s.s	F	
Replicates (R)	5	33·65	9·56**	52·50	40 08**		4	31·65	—	
Main plots (P)	13	5 86	1·66	4·51	3·44**		13	100·39	2·59**	
Main plot × error	65	3·52	—	1·31	—	$\frac{45}{13}\sigma_p^2+\sigma_e^2$	52	38·73	—	$\frac{55}{13}\sigma_p^2+\sigma_e^2$
Years (Y)	8	413·45	175·94**	49·49	29·11**		10	1137·57	37·85**	
R × Y	40	6·22	2·65**	12·88	7·58**		40	39·21	1·30**	
P × Y	32	2·21	—	2·10	1·24		42	31·12	1·04**	
Main plot × year error	160	2·35	—	1·70	—	σ_e^2	168	30·05	—	σ_e^2
Sub-plot (S)	1	8·19	4·20*	0·24	3·00		1	217·61	36·57**	
R × S	5	2·07	1·06	0·39	4·88*		4	4·62	—	
P × S (Adj.)	13	1 69	—	0·44	5·50**		13	5·95	1·55*	
Sub-plot error	65	1·95	—	0·08	—	$\frac{45}{13}\sigma_{sp}^2+\sigma_{sy}^2$	52	3·52	—	$\frac{55}{13}\sigma^2_{sp}+\sigma_s{}^2{}_y$
Y × S	8	1·43	1·51	0 69	1·56*		10	20·86	9·07**	
R × Y × S	40	1·63	1·31**	0·49	1·07*		40	2·60	1·13	
P × Y × S	32	1·21	—	0·43	—		42	2·77	1·20	
Sub-plot × year error	160	1·24	—	0·46	—	σ_{sy}^2	168	2·30	—	$\sigma_s{}^2{}_{\cdot y}$

** Significant at 1%

* Significant at 5%

$\sigma^2{}_p=\sigma^2{}_{mp}+\sigma^2{}_{sp}$

$\sigma^2{}_e=\sigma^2{}_{my}+\sigma^2{}_{sy}$