"On the Efficiency of Designs Used in Animal Experiments"

K. SUBRAHMANIAM,
M.Sc.

Dissertation submitted in part fulfilment for the award of Diploma in Agricultural & Animal Husbandry Statistics of the Institute of Agricultural Research Statistics (I.C.A.R.).

DE-09
4

ACKNOWLEDGEMENTS

The author wishes to place on record the guidance received from Shri V.N. Amble, Assistant Statistical Adviser, I.A.R.S. during the course of the work.

It is also my very pleasant duty to take this opportunity of thanking Dr. G.R. Seth, Statistical Adviser, I.A.R.S. In deed without his persistent inspiration and encouragement this work would, perhaps, not have seen light of the day.

In the end, I wish to thank the Indian Council of Agricultural Research for the opportunity afforded me by way of finance, data and other facilities.

K. Subrahmaniam

(K. SUBRAHMANIAM)

I.A.R.S.
New Delhi.

1. INTRODUCTION.

advances made in the field of animal
go to show that the importance of a well
anned system of experimentation has not been
imal experimenter. The stress laid on the
cts of the studies, whether they concern
th of the animals or the effectiveness of
have helped in drawing valid and logical
the results arrived in the experiments.
tly pointed out that the statistician has
le to play in the field of animal husbandry
ion with the animal husbandry worker can
fective utilization of available resources
ction of the relevant information from the

ntal utility of statistics is to help in
ng of the effects of different factors
he total variation in a body of data. Thus
experimentation one would be interested in
t of treatments do have any effect. But
lusions could be drawn regarding the effects
ts themselves we shall have to seperate out
ctors (apart from the treatments themselves)
to cause a variation in the material under
re the factors of extraneous variation and
ssified into two clases i) those which can
i) others that remain uncontrolled and which

1. INTRODUCTION.

The recent advances made in the field of animal experimentation go to show that the importance of a well organised and planned system of experimentation has not been post upon the animal experimenter. The stress laid on the statistical aspects of the studies, whether they concern the breeding worth of the animals or the effectiveness of a group of feeds have helped in drawing valid and logical conclusions from the results arrived in the experiments. It has been rightly pointed out that the statistician has a much wider role to play in the field of animal husbandry as his cooperation with the animal husbandry worker can result in an effective utilization of available resources and in the extraction of the relevant information from the data.

The fundamental utility of statistics is to help in the distinguishing of the effects of different factors which lead to the total variation in a body of data. Thus in agricultural experimentation one would be interested in finding if a set of treatments do have any effect. But before any conclusions could be drawn regarding the effects of the treatments themselves we shall have to seperate out the numerous factors (apart from the treatments themselves) that are likely to cause a variation in the material under study. These are the factors of extraneous variation and are broadly classified into two clases i) those which can be controlled ii) others that remain uncontrolled and which produce what is termed the error variation.

The effects of treatments can be measured by comparing the variation due to them against the error variation. Since a lesser error will thus help in drawing more sensitive conclusions, it is necessary to minimize the error. Error can be reduced by adopting suitable experimental procedures, though, it can never be eliminated especially in biological experiments. This is what led to the concept of 'local control in experimental designs as also to statistical control.

By local control we mean the suitable grouping of the experimental material into groups which are more or less homogeneous. The criteria for such grouping are suggested from previous observation and experience and are factors closely associated with the variable which is taken to measure the effect of the treatments under experiment, but, where such knowledge is not available or is less definite one method of gaining that information is to carryout an investigation specially for the purpose on a typical experimental material put under uniform treatment. Such an experimentis known as a 'uniformity trial' From the data of such a trial any proposed grouping can be tested for suitability. It may be used to compare different experimental plans by super imposing each on the data of the uniformity trial. Further, the uniformity trial will help to get an idea of the inherent variability in the material.

It would not be out of place to give a summary account of the actual procedure adopted in the agricultural experimentation for conducting uniformity trials.

There have been numerous attempts in agricultural field to define the size, shape and orientation of the experimental plots which would control the error most.

A uniformity trial in agricultural experimentation would consist in laying out on a regular shaped piece of land of well defined dimensions and subjecting it all to same uniform treatment. The crop is then harvested and yield measured dividing the land into very small units of uniform size and shape. A comprehensive compendium of the experiments envisaging the effect of the change in size and shape had been made as early as 1937 by Cochran (2) in his paper in the J.R.S.S.

One of the most important outcomes of the uniformity trials in agricultural experimentation has been the study of the relationship between the variability and the area of a plot made by H. Fairfield Smith (9). The empirical relationship has been of immense importance to agricultural statisticians. Of the latest developments based on his paper mention may be made of Shri Khande's paper on coconut trees (10).

The data obtained in uniformity trial could also be used as concomitant information to reduce error through the application of the covariance technique. The removal of the variation due to the basic variation in the material (as evidenced by the uniformity trial data) could result in more precise comparisons among the treatments.

The draw back in conducting uniformity trial previously to carrying out a regular experiment with the same experimental material is that the labour is doubled without the information being doubled. Further, the uniformity trial delays the actual experimental results by a considerable period of time. In fact, in animal experimentation it seems to be positively unprofitable to under take such trials. There seems to be no record of such trials being laid out seperately in the field of animal experimentation.

In animal experimentation the largest source of error variation is that among animals themselves due to their genetic and physiological dissimilarities. The variability introduced due to the differential yielding ability of the cows is removed to an extent by a proper grouping of the cows. But a very efficient means of achieving this end would be to subjecting every animal in turn to all the treatments. A design which incorporates this idea for reducing the error variation is the one known as a cross over or switch over trial. In addition to eliminating the animal to animal variation the design ensures that the period variation is also eliminated from affecting treatment differences by providing equal number of animals under each treatment in any period. Cochran etal (3) discuss the use of Latin squares for providing such designs. If we were to apply the design in successive lactations the time involved in the completion of the experiment would be inordinately long and the risk of the loss of the animals during the course of experiments great. The designs is more suited to short term experimentation. With the available data on the daily yield records of cows belonging to five herds, the efficiency of the switch-over trials was also investigated.

2. EXTENT AND NATURE OF DATA:

As mentioned in the introduction, no experiments devoted solely to uniformity studies have been laid out any where in the field of animal husbandry. The breeding data collected by the I.A.R.S. for statistical examination were deemed suitable for use as uniformity data. The data consisted of the milk yields records of several herds of cows maintained at a number of livestock research stations spread over India. The herds included in the present studies are:

i) Red Sindhi Herd at the Indian Dairy Research Institute, Bangalore.

ii) Red Sindhi Herd at the livestock research station, Hosur.

iii) Tharparkar Herd at the livestock research station at Patna.

iv) Kangayam Herd at the livestock research station at Hosur.

At these farms the data were recorded in the form of history sheets of the animals maintained there. These sheets included information regarding the date of calving, the order lactation, the lactation yield etc. for various lactations of the cow recorded on the farm. Since our interest lay with the season of calving and the age of the cow measured by the order of lactation, the requisite information was drawn from the history sheets. A cow having a specific abnormality in the course of a lactation was left out of the analysis. These abnormalities included cases of abortion, still birth, mastitis etc.

The fact that the animals were maintained at the same station under common management and those calving in the same year would be receiving the same treatment of feeding and management led to the use of the data as uniformity data.

The data pertaining to the total lactation yields of the cows calving in a particular year were taken as constituting a set for analysis. Normally it would be the practice to select for experimentation animals all calving in the same year, and so it was decided to confine the analysis to the animals calving in one year. Several sets of data were chosen for study such that animals which were included once did not reappear in other sets. This was ensured by leaving a gap of four to seven years between the different years chosen for extraction of data for a set.

A distribution of the animals calving in the different years chosen for study and belonging to the different herds is given below. A detailed table giving the number of animals belonging to the different seasons of calving and orders of lactation is given in the appendix (table 1).

Table (i): Showing the animals in different herds that had calved in the years included in the study.

HERD/ YEAR	1928	1932	1937	1944	1948	1952
Tharparkar	-	-	55	76	61	49
Red Sindhi (Hosur)	36	48	43	49	56	-
Red Sindhi (I.D.R.I.)	13	23	37	41	50	-
Kangayam	27	42	54	68	61	-

The above table, of course, does not include animals which had abnormal yields or which left the farm (due to any reason) before completion of the lactation.

2.1 The analysis of covariance using the preceding lactation yield as concomitant variate involved deletion from the analysis of the animals belonging to the first order of lactation. In some very few cases animals having no normal preceding lactation yield also had to be left out. As a consequence the number of animals which were available was reduced. A split up of the animals belonging to the different herds and calving in the years taken up for study is given below. All the animals belong to orders of lactation higher than the first.

Table (ii): Showing the animals belonging to order of lactation higher than first and calved in different years.

YEAR / HERD	1928	1932	1937	1944	1948	1952
Tharparkar	-	-	33	68	49	42
Red Sindhi (Hosur)	35	47	34	37	50	-
Red Sindhi (I.D.R.I.)	10	25	25	35	37	-
Kangayam	23	29	33	55	34	-

2.2 For the purpose of the study of efficiency of switch over design the available data pertaining to the daily milk yield records of the cows belonging to the following five herds were utilized. The cows were all in the first order of lactation.

Table (iii): Showing the number of animals belonging to different herd and which had complete lactation (daily) yield records.

Herd	No. of animals
1. Hariana (I.V.R.I.)	28
2. Red Sindhi (Hosur)	30
3. Red Sindhi (I.D.R.I.)	30
4. Tharparkar (weaned)	48
5. Tharparkar (unweaned)	34

There being no evidence of any preferential treatment being meted out to any animal at the same farm the sets of data could be used as uniformity trial data.

3. PROCEDURE:

3.1 The details of the nature and extent of the data used in the present work have been discussed in the section 2. As has been pointed out, the basic purpose of this study was to examine the relative efficiencies of the designs that are commonly used in animal experimentation. For preparing the designs the characters which were considered to be of importance for forming homogenous blocks for local control of the environmental variations were two, viz; (i) season of calving and (ii) the age of the cow measured by the order of lactation. One would be led to regard, from a 'priori considerations, that the season of calving could exert an influence on the yield. It is a well known fact that the milk yield is very much controlled by the order of lactation of the cow. Thus, in most herds the yield increases at first attaining a peak in the third or fourth order of lactation and thereafter decreases in later lactations.

The work is divisible, broadly, into three parts: i) the evaluation of the efficiency of the one way and two way classifications by the method of fitting of constants ii) the superimposition and the study of the efficiency of Randomised block and Latin square designs, iii) the use of the covariance procedure for the reduction in error by enforcing statistical control. The randomized block and latin square designs were of sizes 3 and 5 units per blocks, a row & column.

3.1.1. MODEL:

The data pertaining to the cows calving in the same year and belonging to the same herd were classified in accordance with the season of calving and the order of lactation. This classification gave rise to non-orthogonal data - the number of animals calving in the i^{th} season of the year and having the j^{th} order of lactation in that year being n_{ij} Thus, we may represent the yield of the k^{th} cow which has its j^{th} lactation and calves in the i^{th} season as,

$$y_{ijk} = m + a_i + b_j + g_{ij} + e_{ijk}$$

where, m = the general mean effect common to all the cows.

a_i = the effect of ith season. $i = 1,2,3,4.$

b_j = the effect of the jth order of lactation $j = 1,2,3,4,5.$

g_{ij} = the effect of the interaction between the season of calving and the order of lactation.

e_{ijk} = the error variation not attributable to the other factors in the model and are peculiar to the kth cow. The e_{ijk}'s are assumed to be all normally independently distributed with zero mean and common variance $k = 0,1,2.......n_{ij}.$

The analysis of the yields y_{ijk} is done by the usual method of least squares i.e. minimizing the sum of squares of the deviation of y_{ijk} from its expected value with respect to the parameters m, a_i, b_j and g_{ij}. The process of minimization results in a set of equations(one for each parameter involved)- normal equations which when solved the yield the estimates of the parameters in terms of the observations.

3.1.2. NOTATION:

We shall use the following symbolic representation in the following discussion:

$$Y_{ij} = \sum_k y_{ijk} \qquad Y_{i.} = \sum_j \sum_k y_{ijk} \qquad Y_{.j} = \sum_i \sum_k y_{ijk}$$

$Y_{..} = \sum\sum\sum y_{ijk}$ $\quad n_{i.} = \sum_j n_{ij}$ $\quad n_{.j} = \sum_i n_{ij}$ $\quad n_{..} = \sum_i\sum_j n_{ij}$

Further, $Q_i = Y_{i.} - \sum_j \frac{n_{ij}}{n_{.j}} Y_{.j}$

$T = \sum\sum\sum y^2_{ijk}$

3.2.3. NORMAL EQUATIONS:

The least squares procedure yields the following normal equations:

for m $\quad Y_{..} = n_{..}m + \sum_i n_{i.}a_i + \sum_j n_{.j} b_j + \sum_{i,j} n_{ij} g_{ij}$

for a_i $\quad Y_{i.} = n_{i.}m + n_{i.} a_i + \sum_j n_{ij}b_j + \sum_j n_{ij}g_{ij}$ (i=1,2,3,4.)

for b_j $\quad Y_{.j} = n_{.j}m + \sum_i n_{ij}a_i + n_{.j}b_j + \sum_i n_{ij}g_{ij}$ (j=1,2,3,4,5.)

and for g_{ij} $\quad Y_{ij} = n_{ij}(m+a_i+b_j+g_{ij})$

3.1.3: SUMS OF SQUARES:

The sum of squares due to fitted constants is given by the sum of the products of the right hand side of the normal equations by the corresponding estimates. Thus we get

$$mY_{..} + \sum_i a_iY_{i.} + \sum_j b_jY_{.j} + \sum_{i,j} g_{ij}Y_{ij} = \sum_{i,j} \frac{Y^2_{ij}}{n_{ij}}$$

Hence the residual sum of squares after fitting the constants becomes $E = T - \sum_{i,j} \frac{Y^2_{ij}}{n_{ij}}$ which is 'within cells' sum of squares.

3.1.5: ADJUSTED SUMS OF SQUARES:

In order to test for the significance of interaction we shall assume that in the model given previously $g_{ij} = 0$ for all i and j. Eliminating the quantities b_j's from the normal equations as follows:

$Y_{i\cdot} = n_{i\cdot}m + n_{i\cdot}a_i + \sum_j n_{ij} b_j$

$Y_{\cdot j} = n_{\cdot j}m + n_{\cdot j}b_j + \sum_i n_{ij} a_i$

Therefore $b_j = \frac{Y_{\cdot j}}{n_{\cdot j}} - (m + \sum_i \frac{n_{ij}}{n_{\cdot j}} a_i)$

or $Y_{i\cdot} = n_{i\cdot}m + n_{i\cdot}a_i + \sum_j n_{ij} \quad \frac{Y_{\cdot j}}{n_{\cdot j}} - \quad (m + \sum_{i'} \frac{n_{i'j}}{n_{\cdot j}} a_{i'})$

Putting $P_{ii} = n_{i\cdot} - \sum_j \frac{n_{ij}^2}{n_{\cdot j}}$ $\quad P_{ii'} = - \sum_j \frac{n_{ij}\, n_{i'j}}{n_{\cdot j}}$

We get $\quad Q_i = P_{ii}a_i + \sum_{i' \neq i} P_{ii'} a_{i'} \quad i = 1, 2, 3, 4.$

since all these equations are not independent we use the restriction $\sum_i a_i = 0$ and get on eliminating a_4, say,

$Q_1 = P_{11}a_1 + P_{12}a_2 + P_{13}a_3 + P_{14} \times \left\{ - \{ (a_1 + a_2 + a_3) \right\}$

which on simplification becomes

$Q_1 = (n_{1\cdot} - \sum_j \frac{n_{1j}\,(n_{1j} - n_{4j})}{n_{\cdot j}} \quad) a_1 + \sum_j \frac{(n_{4j}(n_{1j} - n_{2j})}{n_{\cdot j}} a_2 + \sum_j \frac{n_{4j}\,(n_{1j} - n_{3j})}{n_{\cdot j}} a_3$

and so on.

~~INTERACTION SUM OF SQUARES~~

The total sum of squares is seen to split up into two parts i) that due to the fitted constants ii) ~~that due to the deviation from the regressions i.e.,~~ residual sum of squares.

As stated previously the sum of squares due to fitted constants is, $(mY_{\cdot\cdot} + \sum_i a_i Y_i + \sum_j b_j Y_j)$ which on eliminating m & b_j becomes

$= \sum_i a_i Q_i + \sum_j \frac{Y_{\cdot j}^2}{n_{\cdot j}}$

The sum of squares due to constants fitted except a_i's is $\sum_j \frac{Y_{\cdot j}^2}{n_{\cdot j}}$ which we shall denote by B and refer to it as the unadjusted S.S. due to B

Hence, the sum of squares due to the age

$\sum_i a_i Q_i$ = (A) as distinct from the sum of squares

$\sum_i \frac{Y_{i.}^2}{n_{i.}} - \frac{Y_{..}^2}{n_{..}} = A$ $\sum_i \frac{Y_{i.}^2}{n_{i.}}$ = A the ~~unadjusted~~ sum of squares due to factor A

The sum of squares due to the constants a's and b's ~~except~~

$$\sum_i a_i Q_i + \left(\sum_j \frac{Y_{.j}^2}{n_{.j}} - \frac{Y_{..}^2}{n_{..}} \right)$$

~~The expression in the brackets is the sum of squares unadjusted due to the factor B.~~ Hence ~~denoting this by B~~ we get the sum of squares due to the constants a's and b's as (A) + B$-\frac{Y_{..}^2}{n_{..}}$. By symmetry this is also equal to (B) + A$-\frac{Y_{..}^2}{n_{..}}$.
Hence A-(A) = B-(B) = Δ, the adjustment factor due to non-orthogonality as defined by Das (4).

3.1.6 <u>INTERACTION SUM OF SQUARES:</u>

The interaction sum of squares is obtained by subtraction of the (A), (B) and the within cell sum of squares from the total adjusted for non-orthogonality. That this is true may be seen from,

$$E = T - A - (B) - I \quad \text{or} \quad I = T - A - (B) - E$$
$$= T' - (A) - (B) - E$$

where $T' = T - \Delta$ and I is the interaction sum of squares.

3.1.7. <u>COVARIANCE:</u>

The model for the case of the covariance is

$$y_{ijk} = m + a_i + b_j + g_{ij} + bx_{ijk} + e_{ijk}$$

where m, a_i, b_j, g_{ij} and e_{ijk} are all defined as before.

x_{ijk} is the preceding lactation yield of the kth cow which is in its jth order of lactation and calves in the ith season.

b is the coefficient of regression of the yield of the cow on its preceding lactation yield.

As before we may define the quantities

$$Y_{ij} = \sum_{k} y_{ijk} \quad Y_{i.} = \sum_{j,k} y_{ijk} \quad Y_{.j} = \sum_{i,k} y_{ijk} \quad Y_{..} = \sum_{i,j,k} y_{ijk}$$

and similarly for the x's

$$X_{ij} = \sum_{k} x_{ijk} \quad X_{i.} = \sum_{j,k} x_{ijk} \quad X_{.j} = \sum_{i,k} x_{ijk} \quad X_{..} = \sum_{i,j,k} x_{ijk}$$

$$Q_i = Y_{i.} - \sum_{j} \frac{n_{ij}}{n_{.j}} Y_{.j} \text{ and } Q_i(x) = X_{i.} - \sum_{j} \frac{n_{ij}}{n_{.j}} X_{.j}$$

The total sum of products $\sum_{i,j,k} x_{ijk} y_{ijk}$ is denoted by T.S.P. The total sum of squares ~~for~~ $\sum x_{ijk}^2$ by $(T.S.S.)_x$, the sums of products $\sum_{j} \frac{Y_{.j} X_{.j}}{n_{.j}}$ and $\sum_{i} \sum_{j} \frac{Y_{ij} X_{ij}}{n_{ij}}$ by B.S.P. and P_{xy} respectively. $\sum_{j} \frac{X_{.j}^2}{n_{.j}}$ by $(B.S.S.)_x$ and $\sum_{ij} \frac{X_{ij}^2}{n_{ij}}$ by T_x^2

NORMAL EQUATIONS:

The least squares procedure yields the following set of equations

$$Y_{..} = n_{..} m + \sum_{i} n_{i.} a_i + \sum_{j} n_{.j} b_j + \sum_{i,j} n_{ij} g_{ij} + bX_{..}$$

$$Y_{i.} = n_{i.}(m + a_i) + \sum_{j} n_{ij} b_j + \sum_{j} n_{ij} g_{ij} + bX_{i.}$$

$$Y_{.j} = n_{.j}(m + b_j) + \sum_{i} n_{ij} a_i + \sum_{i} n_{ij} g_{ij} + bX_{.j}$$

$$(T.S.P.) = mX_{..} + \sum_{i} a_i X_{i.} + \sum_{j} b_j X_{.j} + \sum_{i,j} g_{ij} X_{ij} + b(T.S.S.)_x$$

SUMS OF SQUARES:

As before the sum of squares for fitted constants

$$= mY_{..} + \sum_{i} a_i Y_{i.} + \sum_{j} b_j Y_{.j} + \sum_{i,j} g_{ij} Y_{ij} + b(T.S.P.)$$

Substituting for g_{ij} this becomes

$$\sum_{i,j} \frac{Y_{ij}^2}{n_{ij}} + b(T.S.P. - \sum_{i,j} \frac{X_{ij}Y_{ij}}{n_{ij}})$$

$$= \sum_{i,j} \frac{Y_{ij}^2}{n_{ij}} + \frac{(T.S.P.-P_{xy})^2}{T.S.S. - T_x^2}$$

Since from equations for g_{ij} and b we get the estimate of ba as

$$b = \frac{T.S.P - P_{xy}}{T.S.S_x - T_x^2}$$

Hence, the residual sum of squares is

$$\sum_{i,j,k} y_{ijk}^2 - \sum_{i,j} \frac{Y_{ij}^2}{n_{ij}} - \frac{(T.S.P - P_{xy})^2}{T.S.S._x - T_x^2}$$

Similarly, if we hypothesize the g_{ij} to be absent then the sum of squares due to the constants becomes

$$mY_{..} + \sum_i a_i Y_{i.} + \sum_j b_j Y_{.j} + b(T.S.P.)$$

$$= mY_{..} + \sum_i a_i Y_{i.} + \sum_j b_j Y_{.j} + \frac{(T.S.P - P_{xy})}{(T.S.S._x - T_x^2)} (T.S.P.)$$

which when subtracted from the sum of squares due to all the constants gives the interaction sum of squares as

$$\sum_{i,j} Y_{ij} g_{ij} = \sum_{i,j} Y_{ij} \left(\frac{Y_{ij}}{n_{ij}} - m - a_i - b_j - bX_{ij} \right)$$ which reduces to

$$\sum_{i,j} \frac{Y_{ij}^2}{n_{ij}} + \frac{(T.S.P - P_{xy})^2}{T.S.S._x - T_x^2} - (A) - B$$

where (A) stands for the adjusted sum of square due to the seasons and B the sum of squares due to lactation unadjusted.

(A) and B :

The normal equations can be solved very simply either for a_i or b_j.

Eliminating b_j's we get

$$Q_i = a_i \left(n_{i\cdot} - \sum_j \frac{n_{ij}^2}{n_{\cdot j}}\right) - \sum_k a_k \frac{n_{kj}\, n_{ij}}{n_{\cdot j}} + bQ_{i(x)} \quad i=1,2,3,4.$$

and $(T.S.P - B.S.P) = \sum_i a_i Q_{i(x)} + b \; (T.S.S)_x - (B.S.S.)_x$

Denote $(T.S.P - B.S.P)$ by b' and $(T.S.S)_x$ by a and by c

$\frac{b'}{a}$ then, $c - \frac{\sum_i a_i Q_{ix}}{a} = b$

Hence on putting $Q_i - cQ_{i(x)} = Q'_i$

$$n_{i\cdot} - \sum_j \frac{n_{ij}^2}{n_{\cdot j}} - \frac{Q_{i(x)}^2}{a} = a_{ii}$$

$$-\left(\sum_j \frac{n_{kj} n_{ij}}{n_{\cdot j}} + \frac{Q_{i(x)}\, Q_{kx}}{a}\right) = a_{ik}$$

the normal equations in a_i alone become.

$$Q'_i = \sum_k a_{ik} a_k \qquad (i,\ k=1,2,3,4)$$

As only 3 of these equations are independent the restriction $\sum_k a_k = 0$ is applied. Eliminating a_4 we get

$$Q'_i = a_i P'_{ii} - \sum_k a_k P'_{ik} \quad (i=1,2,3)$$

where $P'_{ii} = P_{ii} - \frac{Q_{i(x)}}{a} \left(Q_{i(x)} - Q_{4x}\right)$

$$P_{ii} = n_{i\cdot} - \sum_j \frac{n_{ij}(n_{kj} - n_{4j})}{n_{\cdot j}}$$

$$P'_{ik} = P_{ik} + \frac{Q_{i(x)}}{a} \left(Q_{i(x)} - Q_{4(x)}\right)$$

and $P_{ik} = \sum_{j} n_{ij} \frac{n_{kj} - n_{4j}}{n_{.j}}$

The total sum of squares is split up into two parts as before.

$$Y_{..} m + \sum_{i} a_i Y_{i.} + \sum_{j} b_j Y_{.j} + b(T.S.P.)$$

Eliminating m, b_js and b interms of a_i this becomes

$$\sum_{i} a_i Q_i' + \sum_{j} \frac{Y_{.j}^2}{n_{.j}} + bc$$

The sum of ~~x~~squares due to fitting cons tants other than a's is equal to $\sum_{j} \frac{Y_{.j}^2}{n_{.j}} + bc$

Hence the sum of squares due to fitting a's alone is $\sum_{i} a_i Q_i'$. This is as before called adjusted sum of squares for the factor A and we denoted by (A). As in the previous case we get (A)+B=(B)+A=sum of squa res due to estimates of all the constants. Hence, A-(A)=B-(B)=Δ the factor of adjustment due to non-orthogonality.

ANALYSIS OF VARIANCE : (Adjusted)

Source of variation	d.f.	S.S.
Between A - classes	3	(A)
Between B - classes	3	(B)
Interaction	9	I=(T)-(A)-(B)-E
Residual	$n_{..}$-16	E
Total	$n_{..}$-1	(T)

3.2 ONE WAY CLASSIFICATION:

The efficiency of the one way classifications possible with the two characters under study were also studied. This was done by starting with the model

$y_{ij}=m+a_i+e_{ij}$ where a_i is the effect of the ith season and e_{ij}'s are error variations and are distributed normally independently with zero means and variances . The method of least squares yields (using the same notation as in section 3.1).

$$Y_{..}=n_{..}m+\sum_i n_{i.}a_i$$
$$Y_{i.}=n_{i.}m+n_{i.}a_i$$

Hence the sum of squares due to the constants a_i's and m is

$$mY_{..}+\sum_i a_iY_{i.}$$
$$=\sum_i \frac{Y_{i.}^2}{n_{i.}}$$

Thus, the sum of squares due to a_i's is $\sum_i a_iY_{i.}=\sum_i \frac{Y_{i.}^2}{n_{i.}}-\frac{Y_{..}^2}{n_{..}}$

Hence error or residual sum of squares is

$$\sum_{i,j} y_{ij}^2-\sum_i \frac{Y_{i.}^2}{n_{i.}}=(T-A).$$

For the case of analysis of covariance we fit the model

$y_{ij}=m+a_i+bx_{ij}+e_{ij}$ the analysis follows very simply by the method of leasts squares.

3.3 SUPER IMPOSITION OF THE DESIGNS:

(a) Randomized Blocks:

Perhaps the most commonly used design in any experimentation is the randomised blocks design. In the adoption of the design there are two factors to be considered i) the nature of the blocks ii) the block size. With regard to the former the season of calving and the order of lactation were taken as the two possible ways of enforcing local control. As for the size of the blocks, we have used blocks of sizes 3 and 5.

The actual super imposition of the design was very simple. The animals were grouped together according to the season of calving and blocks of sizes 3 and 5 formed in the first case. Similarly, blocks of the animals all having the same order of lactation were formed.

An analysis of covariance using the preceding lactation yields was also performed.

(b) Latin Squares:

For the super imposition of latin squares, the two factors viz; season of calving and the order of lactation were taken for forming the rows and columns respectively. The cows were ordered in accordance with the order of lactation to which they belonged and put into columns. Next the cows belonging to the same columns were ordered according to the season of calving. Thus each row had cows calving in the same season but belonging to different orders of lactation. Each column similarly, had cows belonging to same order of lactation but calving in different seasons of the year. Unfortunately, the number of animals in different sets of data did not permit latin squares of sizes beyond 5x5. Latin squares were built up of two different sizes viz: 3x3 and 5x5. An analysis of covariance with the preceding lactation yields also was performed.

ANALYSIS:

In all the cases the usual procedure of analysis of the data for randomized block and latin square designs was followed. The analysis did not present any complications. The covariance technique applied was also the standard one with no changes.

3.3.1. MEASUREMENT OF EFFICIENCY:

A note on the measurement of the efficiency would be in place in that this thesis is primarily concerned with the measurement of efficiencies of different designs.

Cochran and Cox (1) have discussed different ways of measurements of the efficiencies of designs. They have quoted papers on the subjects by Neyman etal (8), Walsh (11) and Fisher (5). The most common measure that has received the maximum usage is perhaps the one due to Fisher. He defines what he calls 'the amount of information' as the reciprocal of the variance in the population. However an observation x subject to error variance whose magnitude itself is not correctly known but is estimated by a mean square s^2 on n degrees of freedom would not give information amounting to $\frac{1}{s^2}$. It has been shown that this amount is given by $\frac{n+1}{n+3} \cdot \frac{1}{s^2}$.

A logical step further.....22

for the comparison of the efficiencies of two designs is to compare the amounts of information supplied by the designs regarding the means. That is

$$\frac{\frac{n_1+1}{n_1+3}\frac{1}{s_1^2}}{\frac{n_2+1}{n_2+3}\frac{1}{s_2^2}}$$

ONE WAY CLASSIFICATION:

The comparison was made between the error variance of the case when there is no classification against the error variance in the one way classification. Similarly for the case of two way classification a comparison of the error variance against the error variance when there is no classification was made. For finding the efficiency of the covariance technique the same procedure ~~has been~~ was adopted. ~~That is,~~ The error variance ~~before the~~ without adjustment for the concomitant variate ~~against~~ was compared with that after ~~the~~ adjustment ~~yielded~~ for eliminating the efficiency of the covariance technique against the analysis of variance procedure. ~~Of course,~~ The adjustment for the differences in the degrees of freedom in the two cases ~~is~~ was made in accordance with the above formula.

3.4. SWITCH OVER DESIGN:

For the convenience of discussion we shall consider the case of 3 treatments A, B & C. In order to eliminate the animal to animal variation every animal is subjected to each of the treatments. Since the yields of the cows are seen to vary with the period of lactation we adopt a design in which in any experimental period on third of the animals receive the sequence A, B, C, one third B, C, A, and one third C, A, B,. so that in each period one third of the animals receive each of the treatments. This is facilitated by the adoption of the latin square of the form

	Cow		
Period	1	2	3
1	A	B	C
2	B	C	A
3	C	A	B

In practice the presence of residual effects complicates matters, and the design has to be modified using orthogonal latin squares for estimating the direct and residual effects seperately. Since in this case there are no different treatments involved these complications do not arise.

There are two methods for allotting the animals to the sequence of treatments. 3r animals say, may either be allotted randomly , r to each treatments or they may be first grouped into r homigenous blocks according to some character such as persistency of milk yield and the three animals in each block allotted at random to the three sequences given by the columns of a latin square. We have tried both the methods in the later case using the milk yield in the first 35 days to form blocks.

Case (i):- Switch over design without blocks:

The analysis in the case of uniformity data in a switch over design without blocks turns out to be when there are m treatments and mr animals :

Source of variation	d.f.	m.s.
Between periods	$(m-1)$	
Between animals	$(mr-1)$	s_2^2
Residual	$(m-1)(mr-1)$	s_1^2
Total	(m^2r-1)	

For the corresponding straight forward design viz; completely randomized design the appropriate error will be given by the means square between animals s_2^2. Hence a comparison of s_1^2 against s_2^2 will give the effiiency of the switch over trial.

Case (ii):- Switch over design with blocks:

The analysis in the case of a switch trial with blocks in uniformity data becomes:

Source of variation	d.f.	m.s.
Periods	$(m-1)$	
Blocks	$(r-1)$	
Animals within blocks	$(rm-r)$	s_4^2
Period into block	$(m-1)(r-1)$	s_5^2
Residual	$(m-1)^2r$	s_3^2
Total	(m^2r-1)	

The efficiency of the switch over h with blocks may be compared against a randomized block design for which the error will be s_4^2 the mean square between animals within blocks. The efficiency of the swithh over design with the blocks relatively to the same design without blocks is obtained by comparing s_3^2 with $\frac{(r-1)s_5^2 + (m-1)rs_3^2}{mr-1}$.

4. RESULTS:

Table II in the appendix presents the efficiency of the one way classifications and the two way classification for the different sets of data. The degrees of freedom available for the residual sum of squares in each case are also presented. The degrees of freedom as was to be expected varied from one set to another. The tharparkar herd provided the largest degrees of freedom ranging from 30 to 50. The Kangayam provided degrees of freedom ranging from 20 to 50. In case of data from Red Sindhi herds at Hosur and Bangalore the degrees of freedom varied from 20 to 30.

The coefficient of variation also was computed and it was found that the values ranged from 30 to 45 percent.

As regards the efficiency, classifications according to the order of lactation gave values lying between 90 and 200 percent, the majority being over hundred. The efficiency of the classification according to the season of calving varied between 95 and 114% with the majority values less than 100. These results are summed up in the following table:

Efficiency(%)	Order of lactation No. of sets of data	Season of calving No. of sets of data
90 -100	4	8
100-120	9	6
over 120	1	-
	14	14

In all the cases of two way classification studied the interaction between the order of lactation and the season of calving was found to be non-significant. This justified the procedure of fitting constants being utilized for estimating the amount of variation attributable to each way of classification.

The two way classification was effective in reducing the variation to a great extent. Excepting in one case the efficiency varied between 95 and 136%. A summary table given below shows the distribution of the efficiency over the different ranges.

Efficiency (%)	Number of cases
Less than 90	1
90-100	3
Over 100	9
	13

Comparing the gains in efficiency of the two way classification over that due to one way classification it was seen that in the case order of lactation in 10 out of 13 sets of data there was a gain in efficiency by the use of the two way classification. This gain in efficiency ranged upto 33%. Similarly the gain in efficiency by the use of two ways classification over the classification due to the season of calving varied between 1 and 39%, there being 12 cases out of the 14 in which there was a gain in efficiency.

Analysis of covariance carried out with the preceding lactation yield as the concomitant variate was seen to be very effective in reducing the error to the extent of 290% in some cases. In most cases the gain in efficiency was seen to be upto 50%.

With the use of the preceding lactation yield as concomitant variate one way classification both with the order of lactation and the season of calving did not result in any improvement. A table giving the summary of the results is given below:

Efficiency (%)	Order of lactation	Season of calving
Less than 90	1	-
90 - 100	8	9
100 - 120	3	5
Over 100	2	-
	13	14

Two way classification however gave better results there being 7 cases out of 14 in which the efficiency was greater than 100 as can be seen from table below:

Efficiency	Number of cases
Less than 90	4
90 - 100	3
Over 100	7
	14

On the whole the use of the two way classification seems to be very effective way of removing the variation dut to the extraneous factors from error. Although the one way classification according to the season of calving is not so very effective as the order of lactation but, as indicated by the results experiments using both together control the error better. Covariance by itself was seem to be a powerful tool for the reduction of error but no gain is obtained in case of the classifications along with covariance procedure.

4.2. Super imposition of designs.

(a) Randomized blocks design:-

~~The super imposition was divided into two parts one of 3 plots the other of 5 plots per block.~~ The system of blocks with the season of calving was not very much effective in controlling error. The increase in size of blocks adversely affected the efficiency.

Order of lactation as a mode of forming blocks was more effective in the reduction of error. The table shows a remarkable gain in efficiency. The block size does not seem to have great influence on the efficiency with this system of block formation. Analysis of covariance technique proved successful. In all the cases ~~it is to be seen~~ that the covariance yielded higher efficiency than a simple analysis of variance.

Thus on the whole the results to indicate that a system of block formation with the order of lactation as blocks is a useful tool for the reduction of error variation whereas date of calving does not very much improve matters. It may be pertinent to point out however, that it may be somewhat effective from the demonstrative value of an experiment to have roughly and equal number of animal under each treatment at any time in an experiment. The grouping of animals according to date of expected calving would be useful from this point of view.

A table giving the distribution of efficiency of super imposition of randomized blocks design is given below:

(i) Analysis of variance

Efficiency (%)	Order of lactation 3 plots	Order of lactation 5 plots	Season of calving. 3 plots	Season of calving. 5 plots
Less than 100	-	4	8	13
100-150	9	8	8	3
150-200	7	3	-	-
Over 200	2	-	-	-
	18	15	16	16

(ii) Analysis of covariance

Efficiency (%)	Order of lactation 3 plots	Order of lactation 5 plots	Season of calving 3 plots	Season of calving 5 plots
Less than 100	-	2	4	7
100-150	8	12	7	7
150-200	7	1	3	-
	15	15	14	14

(b) Latin square design:

The efficiency of the latin squares relative to completely randomized design showed a great deal of variation. The efficiency was greater than 100 in most cases of the 3x3 squares but with squares of size 5x5 it is found that many values fall below 100. A table giving the average values of the efficiency for the different cases studied for the various sets of da ta is given below:

In case of covariance unfortunately there was a lack of sufficient number of cases for averaging in the different sets especially for 5x5 latin s quates. The results are tabulated in the table given below:

Efficiency (%)	Analysis of variance 3x3	Analysis of variance 5x5	Analysis of covariance 3x3	Analysis of covariance 5x5
Less than 100	3	4	4	8
100-150	9	6	10	4
Over 150	4	3	2	1
	16	13	16	13

It is seen from the table that for covariance whereas in the 3x3 squares as many as 12 out of 16 cases have efficiency greater than 100 in the case of 5x5 squares only 5 out of 13 show gain efficiency over the adoption of a completely randomized design with covariance.

A comparison of the one way classification with the approgriate randomized block design was made. In all the cases of 3 plot blocks with order of lactation as a classification r.b.d showed greater gain in efficiency than one way classification. Wheseas in 5 plots blocks the r.b.d. showed more gain in efficiency in 9 out of 13 cases studied. The season of calving for randomized blocks and one way classification showed greater in efficiency in 7 of the 14 cases studied for 3 plot blocks and 10 out of the 14 for 5 plot blocks in favour the former.

4.3 Switch over designs:

The switch over trial gave results which were really remarkable in that the efficiency of switch over with and without blocks was very high as can be seen from Table VII. The values of relative efficiency ranged from 213 to 903 per cent for the case without the formation of blocks and from 107 to 1031 per cent for the case when blocks were formed. Formation of blocks in addition to the adoption of Switchover design resulted only in a gain in efficiency varying from 2 to 28 per cent except in the case of Hariana herd for which the value was 224 per cent. It is thus apparent that the adoption of switchover design is very effective in reducing experimental error.

It should be pointed out however that the adoption of the design requires care when the effect of treatments is slow and the residual effects are likely to be present and last long. The available designs assume that the residual effects last for the duration of only one subsequent period of trial and that the residual effect of a treatment remains the same, no matter which other treatment is applied in the next period. In cases when residual effects are likely to be altogether absent the design would be extremely efficient.

SUMMARY

A study of the relative efficiencies of the designs in more common use in dairy cattle experiments has been made. The two characters used for forming blocks for possible reduction of the error variation were

i) order of lactation

ii) season of calving

The relative efficiency was studied against the total variation present in the data when ~~there is~~ no classification was made. The efficiency gained in eliminating the variation due to the environmental effect of the season of calving and the physiological character viz; order of lactation by the method of fitting of constants was computed. It was found generally that the latter accounts for a greater portion of the variation than the former - a two way classification being in general of much greater ~~use.~~ effectiveness.

The use of covariance ~~which~~ with preceding lactation yields was found to be very beneficial in reducing the error. Super imposition of randomized block using both the season of calving and order of lactation as the possible blocks of sizes 3 and 5 was found to be very efficient. Greater block size tended to reduce the gain in efficiency. ~~Covariance, due to decreasing the number of experimental units available for study, did not improve by any further classification.~~

Latin square could be super imposed only in few cases due to non-availability of sufficient number of animals. But with number of available cases, it ~~is~~ was found that ~~a~~ the design was effective ~~latin squares are every~~ useful in reducing error. ~~The use of covariance made as in the case of randomized blocks design, ill effects on the available material but quite useful in so far as efficiencies are concerned~~

The swithh over design was tried with 3 treatments and periods.

The efficiency of the switch over design with and without blocks was determined. It was found that switch over in all the cases gave very useful results giving very high percentage gain in efficiency.

.-.-.-

REFERENCES.

1. Cochran, W.G. and Cox, G.M.: Experimental designs Johanwiley 1957.
2. Cochran W.G. J.R.S.S. (4) (1937)
3. Cochran W.G. Autrey, K.M. & Cannon, C.Y. J. Dairy Sci. (24) 1941
4. Das, M.N. Jour. Ind. Soc. Agr. Stat. (5)1953
5. Fisher, R.A. The Design of Experiments, Oliver & Boyd, 1947.
6. Fisher, R.A. Statistical Methods for Research Workers, Oliver & Boyd, 1946.
7. Kempthorne, O. The design and analysis of experiments, John Wiley 1952.
8. Neyman, J., with others J.R.S.S. Supp. (2) 1935.
9. Smith, H.F. Jour. Agr. Sci. (28)1938.
10. Shrikhande, V.J. Jour Ind. Soc. Agr. Stat. (9)1959.
11. Walsh, J.E. Jour. Am. Stat. Ass. (44)1949.

Table 1. (A)

Red Sindhi (Hosur).

Number of lactation records pertaining to various orders of lactation and season of calving in different herds.

Lactation order / Season of calving	1	2	3	4	5	Total	1	2	3	4	5	Total
First	1	-	-	2	1	4	3	-	-	-	2	5
Second	1	1	-	2	1	5	-	1	1	1	-	3
Third	-	-	1	2	-	3	3	-	-	-	3	6
Fourth	1	-	-	-	1	2	1	3	-	1	4	9
Total	3	1	-	6	3	13	7	4	1	2	9	23
1937						1944						
First	7	2	2	3	-	14	1	5	1	1	1	9
Second	1	1	-	2	2	6	2	4	2	2	3	13
Third	2	2	-	1	4	9	2	1	2	3	1	9
Fourth	2	2	1	3	-	8	1	2	2	1	4	10
Total	12	7	3	9	6	39	6	12	7	7	9	41
1948												
First	2	4	3	1	1	11						
Second	6	4	2	1	2	15						
Third	2	3	2	1	2	10						
Fourth	3	6	2	1	2	14						
Total	13	17	9	4	7	50						

Table 1 (B)

Red Sindhi Bangalore

Quarter / Order	1928: 1	2	3	4	5	Total	1932: 1	2	3	4	5	Total
First	-	-	4	4	1	9	1	6	1	2	4	14
Second	-	2	1	-	2	5	-	5	1	2	2	10
Third	-	8	1	3	1	13	-	-	4	8	3	15
Fourth	1	5	1	1	1	9	-	-	3	2	5	10
Total	1	15	7	8	5	36	1	11	9	14	14	49

Quarter / Order	1937: 1	2	3	4	5	Total	1944: 1	2	3	4	5	Total
First	1	2	2	2	2	9	2	4	5	3	3	17
Second	2	1	3	-	1	7	2	1	2	1	1	7
Third	1	2	3	1	4	11	5	3	2	1	1	12
Fourth	5	4	-	2	5	16	3	2	2	1	5	13
Total	9	9	8	5	12	43	12	10	11	6	10	49

Quarter / Order	1948: 1	2	3	4	5	Total
First	4	-	-	5	4	13
Second	1	3	3	6	6	19
Third	-	4	2	2	4	12
Fourth	1	4	3	2	2	12
Total	6	11	8	15	16	56

Table 1(C)

KANGAYAM 1928 Order / Quarter	1	2	3	4	5	Total	1932: 1	2	3	4	5	Total
First	-	1	5	2	-	8	1	2	2	-	1	6
Second	2	-	4	-	-	6	5	2	1	2	1	11
Third	1	-	5	2	-	8	4	2	4	3	1	14
Fourth	1	-	3	1	-	5	3	3	-	4	1	11
Total	4	17	5	-	27	13	9	7	9	4	4	42
1937							**1944**					
First	5	2	1	3	1	12	1	4	2	3	7	17
Second	6	3	1	2	1	13	9	5	4	4	5	27
Third	5	2	1	-	3	11	1	1	3	4	7	16
Fourth	5	4	5	3	1	18	2	1	1	2	2	8
Total	21	11	8	8	6	54	13	11	10	13	21	68
1948												
First	3	4	1	1	1	10						
Second	16	1	3	3	2	20						
Third	6	1	2	1	2	12						
Fourth	7	7	2	1	2	19						
Total	27	13	8	6	7	61						

Table I. D. **THARPARKAR:**

Order / Quarter	1937: 1	2	3	4	5	Total	1944: 1	2	3	4	5	Total
First	7	4	6	31	3	21	4	1	7	8	6	26
Second	6	3	4	65	5	23	1	1	2	12	7	23
Third	3	1	7	63	6	20	2	2	2	3	4	13
Fourth	3	1	1	14	1	10	1	1	3	1	8	14
Total	19	9	18	13	15	74	8	5	14	24	25	76

Quarter	1948: 1	2	3	4	5	Total	1954: 1	2	3	4	5	Total
First	3	3	2	3	3	14	2	3	10	3	1	19
Second	4	3	6	5	4	22	1	2	7	1	-	11
Third	1	4	2	1	1	9	2	1	1	2	-	6
Fourth	4	1	6	1	4	16	2	8	1	2	-	13
Total	12	11	16	10	12	61	7	14	19	8	1	49

-.-.-.-.-

Table II.

Table Efficiency of one way classification according to (i) order of lactation ii) season of calving iii) Two-way classification according to the both relative to the case of no -classification.

Herd	Year	Error d.f.	e.v.(%)	order of lactation	season of calving	Two way classification
Harparkar	1952	30	38	92	96	90
	1948	41	35	90	97	104
	1944	56	34	99	100	100
	1937	54	40	103	97	136
Red Sindhi (Hosur)	1948	30	44	103	109	120
	1944	22	30	116	98	117
	1937	17	45	102	97	103
Red Sindhi (Bangalore)	1948	20	32	100	94	95
	1944	29	38	108	105	133
	1937	23	37	119	108	135
Kangayam	1948	41	44	100	96	86
	1944	48	34	107	97	97
	1937	34	43	97	114	133
	1932	22	37	205	100	210

Table III.

Efficiency of one way classification i) order of lactation ii) season of calving as blocks iii) two way classification using lactation as a concomitant vatiation

Herd	Year	Error d.f.	% Eff. of the Cov. Technique	% Eff. of blocks order	% Eff. of blocks Quarter	% Efficiency of 2 way classification
Tharparkar	1952	26	137	93	94	93
	1948	32	186	93	97	93
	1944	51	137	96	105	121
	1937	38	119	99	95	133
Red Sindhi (Hosur)	1948	20	120	104	105	167
	1944	19	233	109	101	111
	1937	8	202	88	99	183
Red Sindhi (Bangalore)	1948	17	100	92	97	88
	1944	20	172	94	94	88
	1937	17	165	134	96	133
Kangayam	1948	17	12	92	98	88
	1944	38	215	103	100	87
	1937	16	211	99	116	121
	1932	12	180	147	97	137.

Table IV.

Average Efficiency of the super imposed randomized blocks according to order of lactation.

Herd		% Efficiencies 3 plots	% Efficiencies 5 plots	Using previous lactation yield as a concomitant variation 3 plots	Using previous lactation yield as a concomitant variation 5 plots
Tharparkar	1952	128	104	132	132
	1948	199	162	190	173
	1944	182	115	178	108
	1937	102	97	101	104
Red Sindhi (Hos ur)	1948	152	84	159	92
	1944	2[illegible]1	104	154	100
	1937	103	103	155	95
	1932	100	-	-	-
	1928	150	-	-	-
Red Sindhi (IDRI)	1948	136	102	175	110
	1944	129	117	142	121
	1937	155	131	162	128
Kangayam	1948	184	94	128	138
	1944	166	152	103	140
	1937	149	92	108	104
	1932	212	168	126	108
	1928	104	105	102	106

-.-.-.-

Table V.

Average efficiency of super-imposed randomized blocks design on the data the season of calving.

Herd		Analysis of variance		Analysis of covariance	
		3 plots	5 plots	3 plots	5 plots.
Tharparkar	1952	90	87	114	91
	1948	88	91	93	95
	1944	120	101	121	107
	1937	121	85	154	99
Red Sindhi (Hosur)	1948	149	108	178	83
	1944	95	98	136	83
	1937	78	86	83	105
	1932	91	97	-	-
	1928	88	91	-	-
Red Sindhi (IDRI)	1948	89	96	92	100
	1944	120	93	132	101
	1937	86	92	92	85
Kangayam	1948	100	87	149	95
	1944	117	96	173	101
	1937	101	91	107	111
	1932	105	135	110	101

-.-.-.-

<u>Table VI.</u>

Showing the efficiencies of super imposed latin squares according to order of lactation and season of calving.

Herd		Average Efficiencies (%) Analysis of variance 3x3	5x5	Herd		Analysis of covariance 3x3	5x5
Tharparkar	1952	96	160	Tharparkar	1952	85	86
	1948	141	110		1948	128	87
	1944	167	90		1944	101	68
	1937	111	95		1937	107	128
Red Sindhi (Hosur)	1948	73	92	Red Sindhi (Hosur)	1948	103	136
	1944	136	136		1944	126	61
	1937	116	102		1937	189	87
	1932	122	-		1932	89	-
	1928	113	-		1928	89	-
Red Sindhi (IDRI)	1948	117	106	Red Sindhi (IDRI)	1948	126	116
	1944	162	137		1944	147	122
	1937	810	206		1937	215	160
	1932	110	-		1932	82	-
Kangayam	1948	94	95	Kangayam	1948	126	87
	1944	115	100		1944	136	83
	1937	160	159		1937	104	81

TABLE VII

The Efficiency of Switchover Design (%)

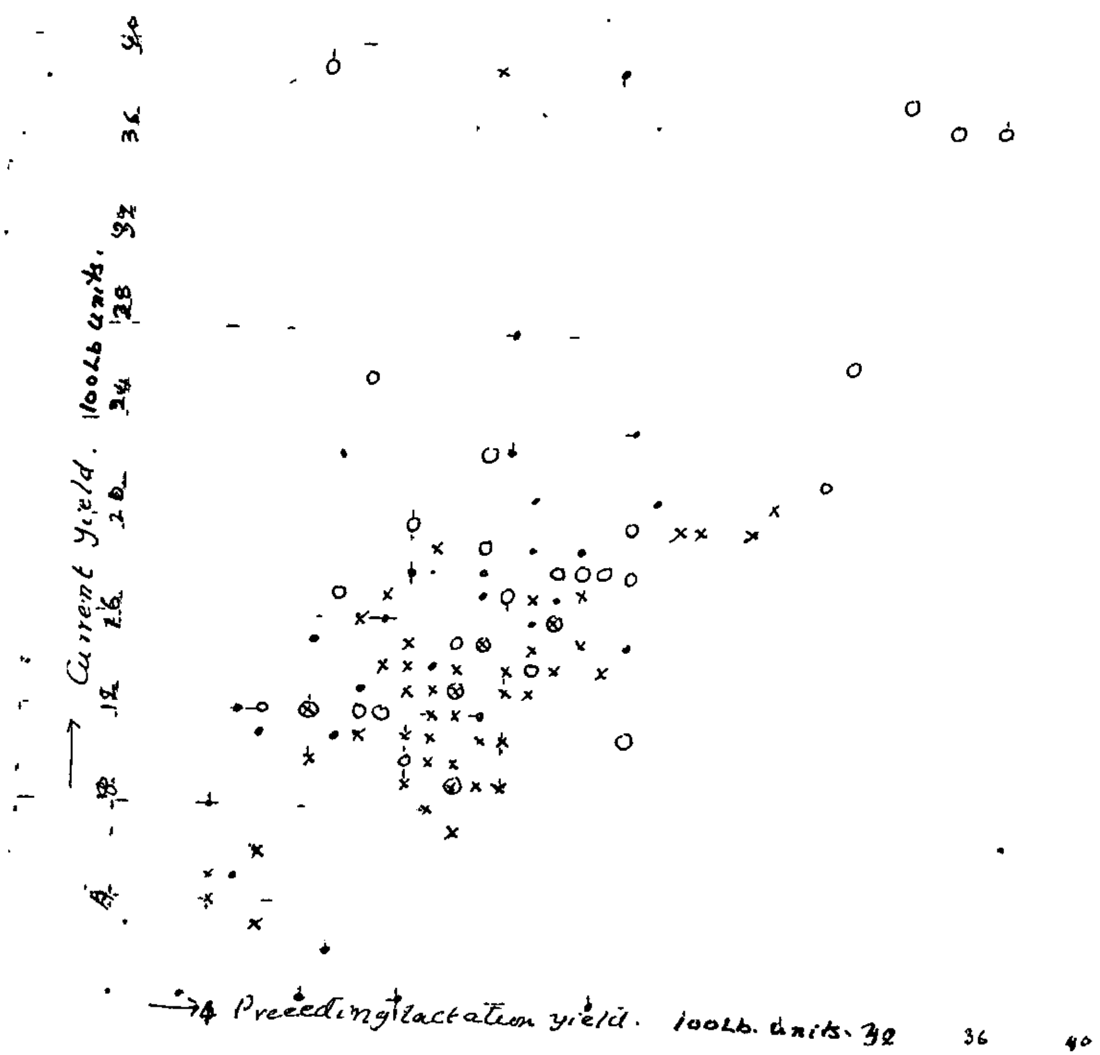
HERD	EFFICIENCY OF SWITCHOVER WITH RESPECT TO SIMPLER DESIGN		EFFICIENCY OF BLOCKS IN SWITCH-OVER
	WITHOUT BLOCKS	WITH BLOCKS	
HARIANA	850	1031	324
REDSINDHI[x]	429	107	102
RED SINDHI[*]	320	419	113
THARPARKAR[1]	903	521	128
THARPARKAR[2]	213	300	107

x HOSUR

* Bangalore

1 Weaned

2 Unweaned.



Scatter diagram showing the distribution of the points (x, y) for the Kangayam

KANGAYAM: 1937, 44, 48

Exemplifying the typical form of distribution in all sets

1937 o
1944 x
1948 •

x: Preceding lactation yields

Y: Current lactation yields.