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A MANUAL FOR THE DESIGN AND ANALYSIS OF ON-FARM TRIALS

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Roger G. Petersen

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DESIGN AND ANALYSIS OF ON-FARM TRIALS

1. INTRODUCTION

The basic goal of On-Farm trials is to compare the results from a package of improved practices with the production system used by the farmer. The trials are relatively simple. Basically they involve two treatments: F = Farmer's practice, and N = Improved practice.

In operation a target area is chosen. This is the area which contains the farm conditions for which the new practices are intended to improve. A number of farms, on which the usual operations are typical of the target area, are chosen for the study. On each of the selected farms a trial is conducted. This trial consists, basically, of two treatments, F and N both of which are used on each of the chosen farms. The increase from the improved practice is then determined by subtracting the response under the farmer's practice, F, from the response under the improved practice, N.

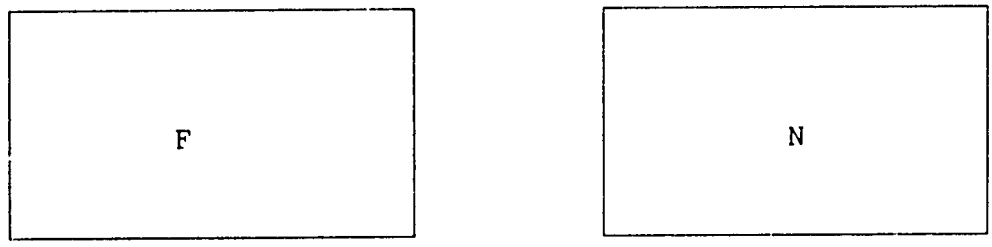
A test of the significance of the increase attributable to the improved practices is based on an analysis of variance of the data from the trials. This analysis of variance provides information which can be used to determine the minimum increase, LSI, which is required to attain significance. The observed increases are then compared against the LSI to determine which, if any, of the increases are significant.

The form of the experimental design to be used on the chosen farms will depend on whether the trial is concerned with animals or crops. Also, with crops the design will depend on whether the improved practice has one or more than one component. Similarly, the analysis of the resulting data will depend on the experimental design used for the trial. The details of the design and analysis will be discussed separately for each of the types of trial involved.

2. ON-FARM TRIALS WITH CROPS

A. Basic Two-Treatment Design

The basic experimental design consists of two large plots on each of a number of selected farms (locations). The plots are laid out in a representative field on the farm. The two plots should be the same size and shape, but they need not be adjacent to each other. The plots should be large enough to permit normal farm operations. One of the plots is assigned to the improved practice (N) while the other is assigned to the farmer's practice (F). The field plan for the basic crops trial on any farm is



The trial is conducted and yield, and other data, are recorded for each plot.

Data analysis: Suppose that the basic two-treatments trial is conducted at each of ℓ locations. The results might be tabulated as follows:

Location	F	N	Difference
1	y_{11}	y_{12}	d_1
2	y_{21}	y_{22}	d_2
.	.	.	.
.	.	.	.
.	.	.	.
1	y_{11}	y_{12}	d_1
	SUM		G
	MEAN		d

Where

y_{ij} = Yield per unit area of the jth treatment at the ith location

d_j = y_{i2} - y_{i1} = Difference between the improved practice and the farmer's practice = increase from the new practice

$G = \Sigma_i d_i =$ Grand total of the differences

$d = G/\ell =$ Mean difference

The data analysis takes a relatively simple form:

Compute $MSE = [1/(\ell - 1)] [\Sigma_i d_i^2 - G^2/\ell]$

The least significant increase, LSI, is computed as

$LSI_{.05} = 1.8 \sqrt{MSE/\ell}$ at the 5% level

$LSI_{.01} = 2.8 \sqrt{MSE/\ell}$ at the 1% level

If $\bar{d} > LSI_{.05}$ the increase over the farmer's practice is significant. (5%)

If $\bar{d} > LSI_{.01}$ the increase over the farmer's practice is highly significant (1%)

If $\bar{d} < LSI_{.05}$ the improved practice is not significantly better than the farmer's practice.

An example of the analysis of data from a basic trial on crops is given in Annex A.

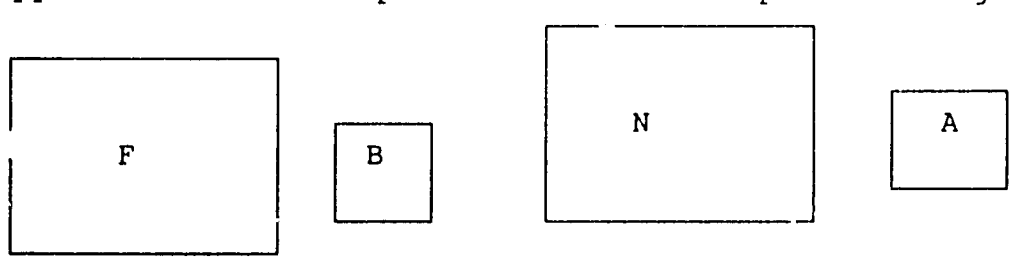
B. Design for Improved Practice with two Components

Often the package of improved practices consists of two types of inputs. For example, the inputs might consist of a new crop variety and the use of an herbicide to control weeds. In this case it might be interesting to determine whether any improvements from the new practice are the result of one or the other of the components or whether both components are acting together. Some information on this question can be obtained by a modification of the basic design.

Suppose the improved practice consists of the addition of two components: A and B. The A component might be variety, for example, and the B component might be herbicide. The trial would be conducted using four treatments:

F = Farmer's practice
N = Improved practice
A = A alone
B = B alone

At each location the experimental design would consist of two large plots, on which treatments F and N would be applied, and two small plots on which the two component treatments, A and B, would be applied. The field plan for the two-component design would be



All of the plots should be located in the same field but they need not be adjacent to each other. The goal is to select plots which are as nearly alike as possible before the treatments are applied.

Data analysis: Suppose that the two-component trial is conducted at each of locations. The resulting data may be tabulated as follows:

	Treatment				
Location	F	N	A	B	SUM
1	y_{11}	y_{12}	y_{13}	y_{14}	L_1
2	y_{21}	y_{22}	y_{23}	y_{24}	L_2
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
1	y_{11}	y_{12}	y_{13}	y_{14}	L_ℓ
SUM	T_1	T_2	T_3	T_4	G
MEAN	y_1	y_2	y_3	y_4	

Where

y_{ij} = Yield per unit area from the jth treatment at the ith location
<u>Note:</u> Because there are different plot sizes the yields must be expressed on a per-unit area basis for the results to be comparable.

$L_i = \Sigma_j\ y_{ij}$ = Total yield at location i

$T_j = \Sigma_i\ y_{ij}$ = Total yield from the jth treatment

$G = \Sigma_i\ L_i = \Sigma_i\ T_j$ = Grand total yield

$\bar{y}_i = T_j/\ell$ = Mean yield of the jth treatment

The data in the table are subjected to an analysis of variance which takes the following form:

ANOVA

SOURCE	df	SS	MS
Total	$4\ell-1$	SSTOT	
Location	$\ell-1$	SSL	
Treatment	3	SST	
Error	$3(\ell-1)$	SSE	MSE

The entries in the ANOVA table are computed as

$$SSTOT = \Sigma_i\ \Sigma_j\ y_{ij}^2 - G^2/4\ell$$

$$SSL = (1/4)\ \Sigma_i\ L_i^2 - G^2/4\ell$$

$$SST = (1/\ )\ \Sigma_j\ T_j^2 - G^2/4\ell$$

$SSE = SSTOT - SSL - SSE$

$MSE = SSE/3(\ell-1)$

Note: The principal reason for completing the ANOVA is to obtain MSE, the experimental error mean square. None of the other mean squares need be computed.

The Mean increases, $\bar{d}_j$, of the other treatments compared to the farmer's practice are computed by subtracting the mean for the farmer's practice, y_1 from the means for the other treatments:

$$\bar{d}_j = \bar{y}_j - \bar{y}_1$$

The smallest increase which will be significant, LSI, is computed as

$LSI_{.05} = 1.8\sqrt{2MSE/\ell}$ at the 5% level

$LSI_{.01} = 2.8\sqrt{2MSE/\ell}$ at the 1% level

If $\bar{d}_j > LSI_{.05}$ the increase is significant (5%)

If $\bar{d}_j > LSI.01$ the increase is highly significant (1%)

If $\bar{d}_j < LSI_{.05}$ the increase is not significant

Components of the Improved Practice: The two components of the improved practice may act independently or may interact with each other to produce an effect. To determine which is the case we partition the treatment source of variation into the main effects and the interaction effect. This partition is accomplished by computing the entries in the following table of contrasts:

	TREATMENT					
EFFECT	F T_1	N T_2	A T_3	B T_4	E_i	S_i^2
A	-	+	+	-	E_A	S_A^2
B	-	+	-	+	E_B	S_B^2
AB	+	+	-	-	E_{AB}	S_{AB}^2

Computations required are:

$$E_A = -T_1 + T_2 + T_3 - T_4 \ , \ S_A^2 = E_A^2/4\ell$$

$$E_B = -T_1 + T_2 - T_3 + T_4 \ , \ S_B^2 = E_B^2/4\ell$$

$$E_{AB} = T_1 + T_2 - T_3 - T_4 \ , \ S_{AB}^2 = E_{AB}^2/4\ell$$

Note: $S_A^2 + S_B^2 + S_{AB}^2 = SST$

We can now test the significance of the main effects and interactions. For this we use an F test.

$F_A = S_A^2/MSE$, with 1, $3(\ell-1)$ df
tests the significance of component A acting alone

$F_B = S_B^2/MSE$, with 1, $3(\ell-1)$ df
tests the significance of the effect of B acting alone

$F_{AB} = S_{AB}^2/MSE$, with 1, $3(\ell-1)$ df
tests the significance of the interaction of component A and component B.

If F_{AB} is significant the two components are not acting independently. In this case the increase from the improved package depends on both components, A and B, being in the package.

If F_{AB} is not significant but either F_A or F_B is then we can look at the increase from the significant component and need not be concerned with the other.

A numerical example of the analysis of data from a two-component improved package is given in annex B.

C. Design for Improved Practice with three Components

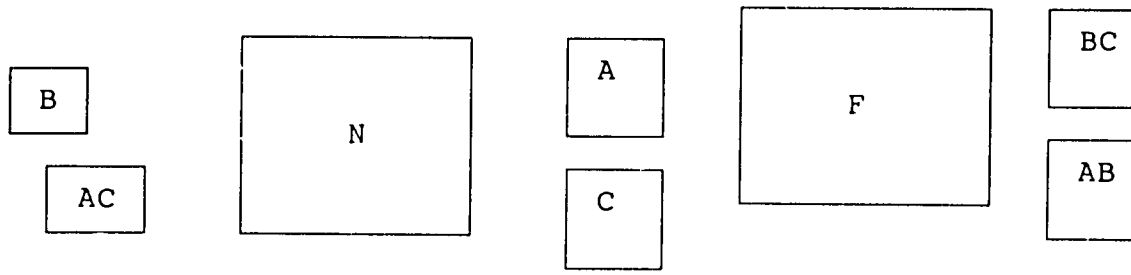
Occasionally the package of improved practices will contain three components. For example, the inputs might consist of (1) an improved variety, (2) an herbicide, and (3) an application of fertilizer. Again, we might be interested in the response to the individual components as well as in the interactions among the components. We can obtain information on the three components using an experimental design which is an extension of the two-component design.

Suppose the improved practice includes three components: A (variety), B (herbicide), and C (fertilizer). The trial would be conducted using eight treatments:

F = Farmer's practice
N = Improved practice
A = Component A alone
B = Component B alone
AB = Both components A and B
C = Component C alone
AC = Both components A and C
BC = Components B and C together

At each farm the design would consist of two large plots, on which treatments F and N would be applied, and six small plots

which would receive treatments A, B, AB, C, AC, and BC. An example of the field plan for this design would be



All of the plots should be located in the same field. They need not be adjacent to each other, but they should be as nearly alike as possible before they are treated.

Data Analysis: Suppose that the three component trial is conducted at each of locations. At the conclusion of the trial the results may be summarized in a data table which takes the following form:

TREATMENT

Location	F	N	A	B	AB	C	AC	BC	SUM
1	y_{11}	y_{12}	y_{13}	y_{14}	y_{15}	y_{16}	y_{17}	y_{18}	L_1
2	y_{21}	y_{22}	y_{23}	y_{24}	y_{25}	y_{26}	y_{27}	y_{28}	L_2
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
ℓ	y_{11}	y_{12}	y_{13}	y_{14}	y_{15}	y_{16}	y_{17}	y_{18}	L_1
SUM	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	G
MEAN	y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8	

Where

y_{ij} = Yield per unit area of the jth treatment at the ith location

$L_i = \Sigma_i\ y_{ij}$ = Total yield at location i

$T_j = \Sigma_i\ y_{ij}$ = Total yield for treatment j

$G = \Sigma_i\ L_i = \Sigma_j\ T_j$ = Grand total yield

$\overline{y}_j = T_j/\ell$ = Mean yield of treatment j

The analysis of variance table for the three-component system takes the following form:

SOURCE	ANOVA df	SS	MS
Total	8 -1	SSTOT	
Location	ℓ -1	SSL	
Treatment	7	SST	
Error	7(ℓ-1)	SSE	MSE

The computations for the entries in the ANOVA table are

$$SST_{OT} = \Sigma_i \Sigma_j Y_{ij}^2 - G^2/8\ell$$

$$SSL = (1/8) \Sigma_i L_i^2 - G^2/8\ell$$

$$SST = (1/\ ) \Sigma_j T_j^2 - G^2/8\ell$$

$$SSE = SST_{OT} - SSL - SST$$

$$MSE = SSE/7(\ell-1)$$

The mean increases, $\bar{d}_j$, of the other treatments over the farmer's practice are computed by subtracting the Mean for the farmer's practice, $\bar{y}_1$, from the other Means:

$$\bar{d}_j = \bar{y}_j - \bar{y}_1$$

The smallest significant increase, LSI, is computed as

$LSI_{.05} = 1.8 \sqrt{2MSE/\ell}$ at the 5% level

$LSI_{.01} = 2.8 \sqrt{2MSE/\ell}$ at the 1% level

If $\bar{d}_j > LSI_{.05}$ the increase is significant (5%)

If $\bar{d}_j > LSI_{.01}$ the increase is highly significant (1%)

If $\bar{d}_j < LSI_{.05}$ the increase is not significant

Components of the Improved Practice: To determine whether the three components interact or are operating independently we partition the treatment source of variation into the main effects and the interaction effects. For this purpose we again set up a table of contrasts. This table takes a form similar to the one used for the two-component system.

	TREATMENT									
EFFECT	F T_1	N T_2	A T_3	B T_4	AB T_5	C T_6	AC T_7	BC T_8	E_i	S^2_i
A	-	+	+	-	+	-	+	-	E_A	S_A^2
B	-	+	-	+	+	-	-	+	E_B	S_B^2

AB	+	+	-	-	+	+	-	-	E_{AB}	S_{AB}^2
C	-	+	-	-	-	+	+	+	E_C	S_C^2
AC	+	+	-	+	-	-	+	-	E_{AC}	S_{AC}^2
BC	+	+	+	-	-	-	-	+	E_{BC}	S_{BC}^2
ABC	-	+	+	+	-	+	-	-	E_{ABC}	S_{ABC}^2

The required computations are:

$$E_A = -T_1 + T_2 + T_3 - T_4 + T_5 - T_6 + T_7 - T_8, \quad S_A^2 = E_A^2/8\ell$$

$$E_B = -T_1 + T_2 - T_3 + T_4 + T_5 - T_6 - T_7 + T_8, \quad S_B^2 = E_B^2/8\ell$$

$$E_{AB} = T_1 + T_2 - T_3 - T_4 + T_5 + T_6 - T_7 - T_8, \quad S^2{}_{AB}{}^2 = EA_B{}^2/8\ell$$

$$\vdots$$

$$E_{ABC} = -T_1 + T_2 + T_3 + T_4 - T_5 + T_6 - T_7 - T_8, \quad S_{ABC}^2 = E_{ABC}^2/8\ell$$

We can now test the significance of the main effects and interactions. For this we use an F test of the form

$$F = S_i^2/MSE, \quad \text{with } 1,\ 7(\ell-1) \text{ df}$$

We begin by testing the three component interaction using

$$F_{ABC} = S_{ABC}^2/MSE$$

If this test is significant none of the components is acting independently and we interpret our results on the basis of the individual treatments considered separately.

If F_{ABC} is not significant we then test the two-component interactions

$$F_{AB} = S_{AB}^2/MSE$$

$$F_{AC} = S_{AC}^2/MSE$$

$$F_{BC} = S_{BC}^2/MSE$$

If any of these tests is significant, F_{AB} for example, the response to one component, A, depends on the presence or absence of the other, B. In this case the interpretation is based on the presence or absence of the two components.

If any of these tests is not significant we test the effects

of the components themselves. For example, if F_{AB} is not significant we test

$$F_A = S_A^2/MSE$$

$$F_B = S_B^2/MSE$$

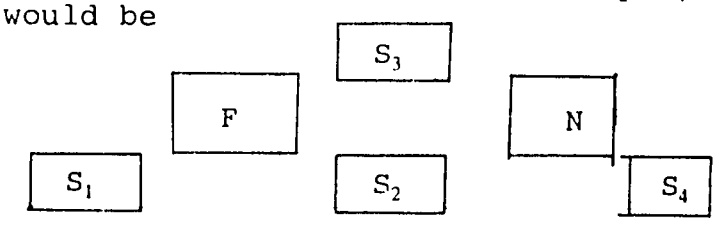
If one of these tests is significant then that component is acting independently. We can interpret the effect of that component without having to consider whether or not the other components are present.

A numerical example of the analysis of data from a three-component package is given in Annex C.

D. Supplementary Treatments

Sometimes it is desired to consider other treatments in addition to the farmer's practice and the improved practice. Further, these other treatments may not be components of the improved practice. For example, it might be of interest to examine a new variety, or a new herbicide which are not included in the improved practice. Further, it might be interesting to see how these supplementary treatments perform in an On-Farm setting.

The basic experimental design for two treatments, F and N, can be modified to include as many as six supplementary treatments, S_1, S_2, ..., S_6, in the trial. The field plan starts with the two large plots in the basic design. Then, as many small plots are added as there are supplementary treatments to be studied. The field plan for such a trial with, for example, four supplementary treatment would be



Again, at each location the plots are located in the same field under conditions which are as nearly alike as possible.

Data Analysis: Suppose that the trial is conducted at each of ℓ locations, and that the treatments include F, N, and p ($0 \leq p \leq 6$) supplementary treatments, S_j. The resulting data may be tabulated as follows:

	TREATMENT						
Location	F	N	S_1	S_2	.....	S_p	SUM
1	y_{11}	y_{12}	y_{13}	y_{14}	.....	y_{1p+2}	L_1
2	y_{21}	y_{22}	y_{23}	y_{24}	.....	y_{2p+2}	L_2
.	.	.	.	.		.	.
.	.	.	.	.		.	.
l	y_{l1}	y_{l2}	y_{l3}	y_{l4}	.....	y_{lp+2}	L_l
SUM	T_1	T_2	T_3	T_4	.....	T_{p+2}	G
MEAN	$\bar{y}_1$	$\bar{y}_2$	$\bar{y}_3$	$\bar{y}_4$	.....	$\bar{y}_{p+2}$	

In which y_{ij} = Yield per unit area of the jth treatment at the jth location

$L_i = \Sigma_j y_{ij}$ = Total yield at location i

$T_j = \Sigma_j y_{ij}$ = Total yield of treatment j

$G = \Sigma_i L_i = \Sigma_j T_j$ = Grand total yield

$\bar{y}_j = T_j/\ell$ = Mean yield of treatment j

The format for the analysis of variance is

SOURCE	ANOVA dt	SS	MS
Total	$\ell(p+2)-1$	SSTOT	
Location	$\ell-1$	SSL	
Treatment	p+1	SST	
Error	$(\ell-1)(p+1)$	SSE	MSE

The computations are much the same as for the other analysis.

$SST_{OT} = \Sigma_i \Sigma_j y_{ij}^2 - G^2/(p+2)$

$SSL = [1/(p+2)] \Sigma_i L_i^2 - G^2/\ell(p+2+$

$SST = (1/\ell) \Sigma_j T_j^2 - G^2/\ell(p+2)$

$SSE = SSTOT - SSL - SST$

Mean increases, $\bar{d}_j$, of the other treatments compared to the farmer's practice are obtained by subtracting the Mean, $\bar{y}_1$, for the farmer's practice from the means for the other

$$\bar{d}_j = \bar{y}_j - \bar{y}_1$$

The least significant increase, LSI, is found to be

$LSI_{.05} = 1.8\sqrt{2MSE/\ell}$ at the 5% level

$LSI_{.01} = 2.8\sqrt{2MSE/\ell}$ at the 1% level

If $\bar{d}_j > LSI_{.05}$ The increase is significant (5%)

If $\bar{d}_j > LSI_{.01}$ The difference is highly significant (1%)

If $\bar{d}_j < LSI_{.05}$ The increase is not significant

A numerical example of an On-Farm trial with supplemental treatment is given in Annex D.

3. ON-FARM TRIALS WITH ANIMALS:

The basic experimental design for On-Farm Trials involving animals is called a cross-over, or simple reversal, design. This is a design for a trial which includes two treatments: Farmer's practice, F, and the improved practice, N. Each trial lasts for two consecutive observation periods. At each farm the animals to be used in the trial are divided into two groups. In one group the animals receive the farmer's practice in the first period and the improved practice in the second period. In the other group the animals receive the treatments in the sequence: Improved practice followed by farmer's practice. The basic pattern is

Period	Group I	Group II
1	N	F
2	F	N

The observation periods should be of equal length and, for most measures, a minimum of four weeks long. The same number of animals should be assigned to each group, although the data analysis is valid if the group sizes are unequal.

Records are kept on each animal for each period. At the conclusion of the trial the mean performance per animal is determined for each group during each period on every farm. These means are the data to be used in the analysis.

Data Analysis: The first step in the analysis is to construct a data table:

GROUP I Period	Treat	LOCATION 1	2	...	ℓ	SUM
1	N	Y_{111}	Y_{121}	...	$Y_{1\ell 1}$	P_{11}
2	F	Y_{112}	Y_{122}	...	$Y_{1\ell 2}$	P_{12}
DIFFERENCE		D_{11}	D_{12}	...	$D_{1\ell}$	G_1
GROUP II		1	2	...	ℓ	
1	F	Y_{211}	Y_{221}	...	$Y_{2\ell 1}$	P_{21}
2	N	Y_{212}	Y_{222}	...	$Y_{2\ell 2}$	P_{22}
DIFFERENCE		D_{21}	D_{22}	...	$D_{2\ell}$	G_2

WHERE:

y_{ijk} = Mean performance per animal on the iTH farm for the jTH group during the kTH period.

D_{ij} = $y_{wl} - y_{ij2}$ = Difference between the first and second period for the ith group on the jth farm.

P_{ik} = Σ_{iyijk} = Total for the ith group during the kth period.

G_i = $P_{i1} - P_{i2} = \Sigma_j D_{ij}$ = Total difference between the first and second period for the ith group.

The analysis of variance of data from a cross-over design has only two lines. The format is as follows:

ANOVA

SOURCE	df	SS	MS
Treatment	1	SST	MST
Error	$2(\ell-1)$	SSE	MSE

The computations are:

$$SST = (G_1 - G_2)^2/4\ell$$
$$SSE = (1/2)(\Sigma_i \Sigma_j D_{ij}^2) - (1/2\ell)(G_1^2 + G_2^2)$$
$$MST = SST$$
$$MSE = SSE/2(\ell-1)$$

The treatment means are computed in the following way:

$\bar{Y}_N = \bar{\bar{Y}} + d$ = Mean of the practice

$\bar{Y}_F = \bar{\bar{Y}} - d$ = Mean of the farmer's practice

Where

$$\bar{\bar{Y}} = (\Sigma_i \Sigma_{ik} P_{ik})/4\ell$$

$$d = (G_1 - G_2)/4\ell$$

The mean increase, from the improved practice compared to the farmer's practice is

$$I_N = \bar{Y}_N - \bar{Y}_F = 2d$$

The minimum difference required for significance, LSI, is computed as

$LSI_{.05} = 1.8\sqrt{MSE/\ell}$ At the 5% level.

$LSI_{.01} = 2.8\sqrt{MSE/\ell}$ At the 1% level.

IF $I_N > LSI_{.05}$ The increase is significant (5%).

IF $I_N > LSI_{.01}$ The increase is highly significant (1%).

IF $I_N < LSI_{.05}$ The increase is not significant.

A worked numerical example of an On-Farm Trial with animals is given in Annex E.

ANNEX A: Basic Two-Treatment Trial on Crops (Numerical Example)

A trial to compare the yield of a new variety of wheat with a commonly grown variety was conducted at eight locations. Two plots were located at each location. The old variety was assigned to one plot and the new variety was assigned to the other. The resulting yields (kg/plot) were as follow:

LOCATION	F	N	$d_i = N_i - F_i$
1	30.2	32.1	2.0
2	31.5	35.6	4.1
3	37.1	41.9	4.8
4	30.8	35.4	4.6
5	23.2	25.4	2.2
6	24,8	27.1	2.3
7	26.7	33.8	7.1
8	26.7	31.1	4.4
		SUM	31.5
		$\bar{d}$	3.94

$$MSE = [1/(8-1)][144.9100 - 992.2500/8]$$
$$= 20.8788/7 = 2.9827$$

$$LSI_{.05} = 1.8\sqrt{2.9827/8} = (1.8)(.6106) = 1.09$$

$$LSI_{.01} = 2.8\sqrt{2.9827/8} = 1.71$$

Since 3.94 > 1.71 the increase from the new variety compared to the common variety is highly significant. The new variety yields about four KG/Plot more than the old.

ANNEX B: Two-component improved practice (Numerical example)

A trial was conducted to measure the response of wheat to an improved package which contained two components: N = New variety and, B = herbicide weed control. The trial was conducted at six locations. At each location there were two large plots: One for the farmer's practice, F, and one for the two-component improved package, N. Also at each location were two small plots: One with the new variety and no herbicide, A, and one with Herbicide and the farmer's variety, B.

Wheat yields (BU/A) are given in the following table:

	TREATMENT				
LOCATION	F	N	A	B	SUM
1	61	60	65	60	246
2	56	62	60	60	238
3	58	58	61	59	236
4	45	68	61	50	224
5	55	56	60	54	225
6	43	67	50	45	205
SUM	318	371	357	328	1374
MEAN	53.00	61.83	59.50	54.67	

The analysis of variance for this set of data is

ANOVA

SOURCE	df	SS	MS
Total	23	1,004.50	
Location	5	259.00	
Treatment	3	304.83	
Error	15	440.67	29.38

The increases from the new package and its components compared

to the farmer's practice are

Treatment	N	A	B
	8.83	6.50	1.67

For this trial the least significant increase LSI, is

$$LSI_{.05} = 1.8 \sqrt{(2)(29.88)/6} = 5.63$$

$$LSI_{.01} = 2.8 \sqrt{(12)(29.38)/6} = 8.76$$

Since 8.83 > 8.76 the increase from the improved practice is highly significant.

Since 8.76 > 6.50 > 5.63 the increase from the new variety alone is significant.

Since 1.67 < 5.63 the increase from herbicide alone is not signficant.

Main effects and interactions of the components are examined by constructing the following table of contrasts:

EFFECT	TREATMENT F 318	N 371	A 357	B 328	E_i	S^2_i
A	-	+	+	-	82	280.17
B	-	+	-	+	24	24.00
AB	+	+	-	-	4	.66

For example

$$E_A = (-318) + 371 + 357 + (-328) = 82$$

$$S^2_A = (82)^2 / (4)(6) = 6724/24 = 280.17$$

Note: 280.17 + 24.00 + .66 = 304.84 = SST

The significance of these effects is tested using an F test.

$$F_A = 280.17 / 29.38 = 9.54$$

$$F_B = 24.00 / 29.38 = .82$$

$$F_{AB} = .66 / 29.38 = .02$$

$$F_{.01}(1,15) = 8.68$$

$$F_{.05}(1,15) = 4.54$$

The factor A (variety) effect is highly significant. Neither the factor B effect nor their interaction is signficant.

The results may be summarized in the following table of mean yields:

Mean Yield (BU / A) of Wheat.

VARIETY	HERBICIDE NO	HERBICIDE YES	MEAN
OLD	53.00	54.67	53.84
NEW	59.50	61.83	60.66
MEAN	56.25	58.25	57.25

It is seen that, on average, the new variety outyields the old variety by almost seven BU/A. On the other hand Weed Control had no real effect on yield, nor did the increase from the new variety depend on whether or not weed control was used.

ANNEX C: Three-Component improved practice (Numerical example)

An On-Farm Trial was conducted in Baluchistan to compare an improved system with the farmer's practice on the yield of lentils. The improved practice included three components: A = Addition of Potassium Fertilizer (K), B = Addition of Phosphorus Fertilizer (P), and reduced seed rate (R). The trial was conducted at three locations. At each location there were two large plots on which were appled the farmer's practice, F, and the improved practice, N. In addition, there were six small plots in the same field as the large plots at each location. On these small plots the following treatments were used:

A	=	K Alone	C	=	Improved Rate Alone
B	=	P Alone	AC	=	Improved Rate + K
AB	=	K + P	BC	=	Improved Rate + P

Lentil yields (T/HA) are shown in the following:

LOCATION	TREATMENT F	N	A	B	AB	C	AC	BC	SUM
1	0.6	2.8	1.0	1.8	1.5	1.3	1.7	2.2	12.9
2	1.3	3.2	1.7	1.6	2.0	1.3	1.8	2.0	14.9
3	1.1	3.1	1.8	2.3	2.2	2.2	1.9	2.7	17.3
SUM	3.0	9.1	4.5	5.7	5.7	4.8	5.4	6.9	45.1
MEAN	1.00	3.03	1.50	1.90	1.90	1.60	1.80	2.30	

The analysis of variance of the lentil yields takes the form

ANOVA

SOURCE	df	SS	MS
Total	23	9.5996	
Location	2	1.2133	
Treatment	7	7.5329	
Error	14	.8504	.0607

The mean increases from the improved package and its components compared to the farmer's practice are

TREATMENT	N	A	B	AB	C	AC	BC
INCREASE, $\bar{d}_j$	2.03	.50	.90	.90	.60	.80	1.30

The least significant increase, LSI, for this trial is

$$LSI_{.05} = 1.8 \sqrt{(2)(.0607)/3} = 0.36$$

$$LSI_{.01} = 2.8 \sqrt{(2)(.0607)/3} = 0.56$$

Increases from all treatments except A are greater than 0.56. Hence all except A are highly significant. Since 0.36 < 0.50 < 0.56 treatment A is significant at the 5% level.

Main effects and interactions among the there components of the improved practice are examined in a table of contrasts:

EFFECT	F 3.0	N 9.1	A 4.5	B 5.7	AB 5.7	C 4.8	AC 5.4	BC 6.9	E	S^2_i	F
A	-	+	+	-	+	-	+	-	4.3	.7704	12.69
B	-	+	-	+	+	-	-	+	9.7	3.9204	64.59
AB	+	+	-	-	+	+	-	-	.1	.0004	.01
C	-	+	-	-	-	+	+	+	7.3	2.2204	36.58
AC	+	+	-	+	-	-	+	-	1.3	.0704	1.16
BC	+	+	+	-	-	-	-	+	1.9	.1504	2.48
ABC	-	+	+	+	-	+	-	-	3.1	.4004	6.60

From the F Table we find
F.05(1,14) = 4.60
F.01(1,14) = 8.86

Comparing the F's for the contrasts with those from the table we find that A, B, and C main effects are highly significant while the three factor interaction is significant at the 5% level. None of the two-factor interactions are significant.

Although there is some indication that the three components are not acting independently, it is clear that the individual components are effective. Further, this effect is present regardless of the presence or absence of the other components. The results may be summarized in the following table of mean yields:

	PRACTICE	
	FARMER	IMPROVED
K	1.70	2.06
P	1.48	2.28
SEED RATE	1.58	2.18

It is seen that the addition of K fertilizer results in an average increase of 0.36 T/HA, the addition of P fertilizer results in an increase, on average, of 0.80 T/HA, and the improved seed rate gives a 0.60 T/HA increase in the yield of lentils.

ANNEX D: FSR Crop Trial with supplementary treatments (Numerical example)

An On-Farm Trial was conducted to compare a package of improved practices, N, with the usual farmer's practice in the rice growing area of Pakistan. At the same time, four supplementary treatments, S1, S2, S3, S4, were studied. The trial was conducted at five locations.

Rice yields (T/HA) are given in the followirg data table:

LOCATION	TREATMENT F	N	S1	S2	S3	S4	SUM
1	3.21	4.45	4.50	4.46	3.68	4.20	24.50
2	3.31	4.89	5.10	4.79	4.21	4.31	26.61
3	3.86	5.68	6.10	5.67	4.72	4.89	30.92
4	3.74	5.47	6.40	5.21	4.80	4.77	30.39
5	3.99	6.01	7.18	5.79	5.28	5.39	33.64
SUM	18.11	26.50	29.28	25.92	22.69	23.56	146.06
MEAN	3.62	5.30	5.86	5.18	4.54	4.71	

ANOVA

SOURCE	df	SS	MS
Total	29	24.9997	
Location	4	8.8142	
Treatment	5	14.7419	
Error	20	1.4436	.0722

The increases from the other treatments over the farmer's practice are

TREATMENT	N	S1	S2	S3	S4
$\bar{d}$ (T/HA)	1.68	2.24	1.56	0.92	1.09

For this set of price yield data the least significant increases are:

$$LSI_{.05} = 1.8 \quad (2)(.0722)/5 = .31$$

$$LSI_{.01} = 2.8 \quad (2)(.0722)/5 = .48$$

All of the increases are greater than 0.48. Hence, the improved practice and the four supplementary treatments produced highly significant increases over the farmer's practice.

ANNEX E. On-Farm Trial with Animals (Numerical Example)

A feeding trial was conducted to measure the gain produced by feeding a protein supplement, N, along with the farmer's usual ration, F. Flocks of sheep at four farms were divided into two groups. One group was fed the farmer's ration, F, while the other received the standard ration plus the protein supplement, N. The trial lasted for two 30 day periods. A cross-over experimental design was used. Average gain per animal was measured for each period for each group.

The resulting mean gains (KG) per animal are given in the following table:

GROUP I		FARM				
GROUP	TREAT	1	2	3	4	SUM
1	N	98	89	85	82	354
2	F	70	72	61	59	262
DIFFERENCE		28	17	24	23	92
1	F	72	83	90	67	312
2	N	96	96	101	88	381
DIFFERENCE		-24	-13	-11	-21	-69

Computations: Example

$$D_{11} = Y_{111} - Y_{112} = 98-70 = 28$$
$$P_{11} = \Sigma_j Y_{1j1} = 98 + 89 + 85 + 82 = 354$$
$$G_1 = P_{11} - P_{12} = 354 - 262 = 92$$

The analysis of variance for this set of data is

ANOVA

SOURCE	df	SS	MS
Treatment	1	1620.06	1620.06
Error	6	89.38	14.90

Computations:

$$SST = (G_1 - G_2)^2/4 = [92 - (-69)]^2/(4)(4) = 1620.06$$

$$SSE = (1/2)\Sigma_i\Sigma_j D^2_{ij} - (1/2\ell)(G_{12} + G_2^2)$$

$$= (1/2)[28^2+17^2 + \ldots + (-21)^2] - [1/(2)(4)][92^2 + (-69)^2]$$
$$= 1742.50 - 1653.125$$
$$= 89.38$$

$$MST = SST = 1620.06$$
$$MSE = SSE/2(\ell-1) = 89.38/6 = 14.90$$

Treatment means:

$$\bar{\bar{Y}} = \Sigma_i\Sigma_k P_{ik}/4\ell$$

$$= (354 + 262 + 312 + 381)/(4)(4) = 81.81$$

$$d = (G_1 - G_2)/4$$
$$= [92 - (-69)]/(4)(4) = 10.06$$

$$\bar{Y}_N = Y + d = 81.81 + 10.06 = 91.87$$

$$Y_F = \bar{\bar{Y}} - d = 81.81 - 10.06 = 71.75$$

$$I_N = \bar{Y}_N - \bar{Y}_F = 2d = (2)(10.06) = 20.12$$
$$= \text{Mean increase from protein}$$

Least significant increase, LSI, is

$$LSI_{.05} = 1.8\sqrt{MSE/\ell} = 1.8\sqrt{14.90/4}$$
$$= 3.47$$

$$LSI_{.01} = 2.81\sqrt{MSE/\ell} = 2.8\sqrt{14.90/4}$$
$$= 5.40$$

Since 10.06 > 5.40 the increase from protein supplement is highly significant. Protein increases lamb gain by about 10 KG. per animal.