Chapter 7

Strip Plot Design

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Abstract

The strip plot design is one of the uncommon experimental designs and thus most researchers had little or no knowledge of it. Though it has semblance of the split plot design, it is used differently. This paper examines conditions or situations that necessitate the use of the strip plot designs and explains comprehensively with designed examples of experiments on how to handle such designs. The chapter examines the factor that is mainly used when greater precision is given to the interactions between the two factors. It also shows how the two factors are arranged in the design.

Keywords

Horizontal Strips, Vertical Strips, Interaction Strips, Design

7.1 Introduction

The strip plot design is most uncommon and less used design. However its use becomes necessary when the experimenter or the researcher needs to handle certain experiments. It used for analysing two factor experiments in which the factors to be handled are so large that they cannot be accommodated in a split plot design or would bring about a condition of heterogeneity in terms of the factors being considered. For instance in a two factor (subplot factor and main factor) experiment which involves testing the effects of four (4) tillage methods - *subplot factor*; and four (4) soil types - *main plot factor* on productivity of crops. In the design of such an experiment since large space is involved, it cannot be accommodated in a split plot design because large land space is needed and this would bring about heterogeneity. As a result the appropriate design for such experiment would be the strip plot design. In the strip plot design, the factors are handled by arranging them in strips. The factors are arranged and placed in a horizontal strip, vertical strip and interaction strip. One factor is placed in the horizontal strip and the second factor in the vertical strip; and the interactions between the factors placed in the vertical and horizontal strips are observed in the interaction strip, which is diagonal to the vertical and the horizontal strips.

While in the split plot designs, greater precision is given to the subplot factors while sacrificing that of the main plot factors; in strip plot designs, the precision for both the main plot factors and the subplot factors are sacrificed to give greater precision to only their interactions. Thus this design is only used when the experimenter needs to give greater precision to the interactions between the two factors being considered in an experiment. Usually in a strip plot design, the subplot factors are arranged by randomizing and placed within the horizontal strips while the main plot factors are placed in the vertical strips. The interactions between both factors are then seen or observed diagonally between the spaces or field between the vertical and horizontal strips as in the diagrammatic illustration given below:

REPLICATION 1				
B1	B1A1	B1A2	B1A3	B1A4
B2	B2A1	B2A2	B2A3	B2A4
B3	B3A1	B3A2	B3A3	B3A4
B4	B4A1	B4A2	B4A3	B4A4
	A1	A2	A3	A4

REPLICATION 2				
B2	B2A2	B2A3	B2A4	B2A1
B3	B3A2	B3A3	B3A4	B3A1
B4	B4A2	B4A3	B4A4	B4A1
B1	B1A2	B1A3	B1A4	B1A1
	A2	A3	A4	A1

REPLICATION 3				
B3	B3A3	B3A4	B3A1	B3A2
B4	B4A3	B4A4	B4A1	B4A2
B1	B1A3	B1A4	B1A1	B1A2
B2	B2A3	B2A4	B2A1	B2A2
	A3	A4	A1	A2

For the purpose of illustrating and explaining the strip plot design, we proceed to design a strip plot experiment and learn how to analyze it. Assuming we are considering a strip plot experiment to study the effect on four (4) tillage methods on four (4) different soil types, we will have a similar design as given above, where the variables B are the sub plot factors arranged in the vertical strip and A, the main plot factors arranged the horizontal whereas the interaction between the subplot factor and the main plot factor.

Thus in the experimental layout, the vertical strip must be divided into four to contain the four different levels of the main factor A; the horizontal strip must also be divided into four to contain the four different levels of the second factor B. The interaction between the two factors A and B (A x B) is observed in the interaction strip. This is done for every replication. Therefore if three (3) replications are to be considered, then the arrangement is done three times.

Analysis of this design is done in three-fold: analyzing the vertical strip, the horizontal strip and the interaction strip. The vertical analysis is done by first creating a cross table of the replication and the main factor which in this case is A. The analysis of the design involves computing the Sum of Squares (SS) due to the main factor (A); SS due replication; SS due to the interactions between the main factor (A) and replication (R) – A x R; and then the error SS (x). The horizontal strip analysis involves creating a cross table of the second factor and the replication and using it to compute the SS due to the second factor (B); SS due to the replications; SS due to the interaction between B x R; and the SS due to error (y). For the analysis of the interaction strip, the cross table of the main factor and the second factor is generated and then used in computing the SS due to the interaction of two factors (A x B). Thus the Total SS can be computed by considering every observation of the experiment while the error SS (z) can be obtained by subtracting all various variations from the Total SS variations.

Now let us assume a researcher used strip plot design to investigate the effect of four tillage methods (A) and four different soil types (B) with the experiment replicated three (3) times and obtained the results as shown in the table below:

REPLICATION 1				
B2	1.3	1.4	1.3	1.1
B3	1.5	1.4	1.5	1.3
B4	1.4	1.6	1.5	1.6
B1	1.4	1.2	1.7	1.3
	A2	A3	A4	A1

REPLICATION 2				
B1	1.3	1.4	1.4	2.3
B2	1.4	1.5	1.5	1.3
B3	1.5	1.3	1.3	1.4
B4	1.8	1.3	1.4	1.4
	A1	A2	A3	A4

REPLICATION 3				
B2	2.4	1.6	1.3	2.1
B3	1.6	2.0	1.5	2.0
B1	2.4	1.6	1.4	1.9
B4	1.4	1.5	1.7	1.8
	A4	A3	A1	A2

		A_1	A_2	A_3	A_4
REPLICATION 1	B_2	1.1	1.3	1.4	1.3
	B_3	1.3	1.5	1.4	1.5
	B_4	1.6	1.4	1.6	1.5
	B_1	1.3	1.4	1.2	1.7
REPLICATION 2	B_1	1.3	1.4	1.4	2.3
	B_2	1.4	1.5	1.5	1.3
	B_3	1.5	1.3	1.3	1.4
	B_4	1.8	1.3	1.4	1.4
REPLICATION 3	B_2	1.3	2.1	1.6	2.4
	B_3	1.5	2.0	2.0	1.6
	B_1	1.4	1.9	1.6	2.4
	B_4	1.7	1.8	1.5	1.4

7.2 For the Vertical Strip Analysis

Cross tabulation of Replication and Tillage Method (R x A)

	A1	A2	A3	A4	Rep Totals
REPLICATION I	5.3	5.6	5.6	6.0	22.5
REPLICATION II	6.0	5.5	5.6	6.4	23.5
REPLICATION III	5.9	7.8	6.7	7.8	28.2
Tillage Method Totals	17.2	18.9	17.9	20.2	
Grand Total					74.2

Calculating the Grand Total (GT)

$$GT = \sum_{i=1,j=1}^{n=12} (5.3 + 5.6 + 5.6 + 6.0 + \cdots + 7.8) = 74.2$$

Calculating the Correction Factor (CF)

$$CF = \frac{(GT)^2}{rab}$$

$$CF = \frac{(74.2)^2}{3\ x\ 4\ x\ 4}$$

$$CF = \frac{5505.64}{48}$$

$$CF = 114.70$$

where r=no. of replications a=no. of levels of tillage methods, b=no. of levels of soil.

At this point one must compute the sum of squares for items or factor within the vertical strip and these are done be done and illustrated below:

Calculating the Total Sum of Squares (TSS)

$$TSS = \sum sum\ of\ square\ of\ all\ observations - CF$$

$$TSS = \sum_{i=1,j=1,k=1}^{n=48} (a_1 b_1 r_1)^2 + \ \dots\dots\dots\dots\dots + (a_2 b_3 r_3)^2 - CF$$

$$TSS = \sum[(1.1)^2 + (1.3)^2 + (1.4)^2 + (1.3)^2 + \cdots + (1.4)^2] - 114.70$$

$$TSS = \sum[1.21 + 1.69 + 1.96 + 1.69 + \cdots + 1.96] - 114.70$$

$$TSS = 118.96 - 114.70$$

$$TSS = 4.26$$

Calculating the Replication Sum of Squares (RSS)

$$RSS = \sum \frac{[(R_{1T})^2 + (R_{2T})^2 + (R_{3T})^2]}{ab} - CF$$

$$RSS = \sum \frac{[(22.5)^2 + (23.5)^2 + (28.2)^2]}{4\ x\ 4} - 114.70$$

$$RSS = \sum \frac{[\ 506.25 + 552.25 + 795.24]}{16} - 114.70$$

$$RSS = \sum (\frac{[1853.74]}{16} - 114.70)$$

$$RSS = 115.86 - 114.70$$

$$RSS = 1.16$$

Calculating the Tillage Method Sum of Squares (ASS)

$$ASS = \sum \frac{[(A_{1T})^2 + (A_{2T})^2 + (A_{3T})^2 + (A_{4T})^2]}{br} - CF$$

$$ASS = \sum \frac{[(17.2)^2 + (18.9)^2 + (17.9)^2 + (20.2)^2]}{4\ x\ 3} - 114.70$$

$$ASS = \sum \frac{[\ 295.84 + 357.21 + 320.41 + 408.04]}{12} - 114.70$$

$$ASS = \sum (\frac{[\ 1381.5]}{12} - 114.70)$$

$$ASS = 115.13 - 114.70$$

$$ASS = 0.42$$

Calculating the Replication and Tillage Method Sum of Squares (RASS)

Note: one is expected to use the cross tabulation table for replication and machine type

$$RASS = \sum_{i=1,j=1}^{n=12} \frac{(A_1r_1)^2 + \dots\dots\dots\dots\dots + (A_2r_3)^2}{b} - CF$$

$$RASS = \sum \frac{[(5.3)^2 + (5.6)^2 + (5.6)^2 + \cdots + (7.8)^2]}{4} - 114.70$$

$$RASS = \sum \frac{[28.09 + 31.36 + 31.36 + \cdots + 60.84]}{4} - 114.70$$

$$RASS = \sum \frac{[466.76\ ]}{4} - 114.70$$

$$RASS = (116.69 - 114.70)$$

$$RASS = 1.99$$

$$\text{Error (x)Sum of Squares (for the vertical strip)} = RASS - RSS - ASS$$

$$E(x)SS = RASS - RSS - ASS$$

$$E(x)SS = 1.99 - 1.16 - 0.42$$

$$E(x)SS = 0.41$$

7.3 For the Horizontal Strip Analysis

Cross tabulation of Replication and Soil Type (R x B)

	B1	**B2**	**B3**	**B4**	**Rep Totals**
REPLICATION I	5.6	5.1	5.7	6.1	22.5
REPLICATION II	6.4	5.7	5.5	5.9	23.5
REPLICATION III	7.3	7.4	7.1	6.4	28.2
Soil Type Totals	19.3	18.2	18.3	18.4	
Grand Total					74.2

Calculating the Replication Sum of Squares (RSS)

$$RSS = \sum \frac{[(R_{1_T})^2 + (R_{2_T})^2 + (R_{3_T})^2]}{ab} - CF$$

$$RSS = \sum \frac{[(22.5)^2 + (23.5)^2 + (28.2)^2]}{4 \ x \ 4} - 114.70$$

$$RSS = \sum \frac{[\ 506.25 + 552.25 + 795.24]}{16} - 114.70$$

$$RSS = \sum (\frac{[1853.74]}{16} - 114.70)$$

$$RSS = 115.86 - 114.70$$

$$RSS = 1.16$$

Calculating the Soil Type Sum of Squares (BSS)

$$BSS = \sum \frac{[(B_{1_T})^2 + (B_{2_T})^2 + (B_{3_T})^2 + (B_{4_T})^2]}{ar} - CF$$

$$BSS = \sum \frac{[(19.3)^2 + (18.2)^2 + (18.3)^2 + (18.4)^2]}{4 \ x \ 3} - 114.70$$

$$BSS = \sum \frac{[\ 372.49 + 331.24 + 334.89 + 338.56]}{12} - 114.70$$

$$BSS = \sum (\frac{[\ 1377.18]}{12} - 114.70)$$

$$BSS = 114.77 - 114.70$$

$$BSS = 0.07$$

Calculating the Replication and Tillage Method Sum of Squares (RBSS)

Note: one is expected to use the cross tabulation table for replication and machine type

$$RBSS = \sum_{i=1, j=1}^{n=12} \frac{(B_1 r_1)^2 + \ \ldots \ldots \ldots \ldots \ldots + (B_2 r_3)^2}{a} - CF$$

$$RBSS = \sum \frac{[(5.6)^2 + (5.1)^2 + (5.7)^2 + \cdots + (6.4)^2]}{4} - 114.70$$

$$RBSS = \sum \frac{[31.36 + 26.01 + 32.49 + \cdots + 40.96]}{4} - 114.70$$

$$RBSS = \sum \frac{[465\ ]}{4} - 114.70$$

$$RBSS = (116.25 - 114.70)$$

$$RBSS = 1.55$$

Error (y) Sum of Squares (for the horizontal strip) $= RBSS - RSS - BSS$

$$E(y)SS = RBSS - RSS - BSS$$

$$E(y)SS = 1.55 - 1.16 - 0.07$$

$$E(y)SS = 0.32$$

7.4 For the Interaction Strip Analysis

Cross tabulation of Tillage Method (A) and Soil Type (B) (A x B)

	A1	**A2**	**A3**	**A4**	**B Totals**
B1	4.0	4.7	4.2	6.4	19.3
B2	3.8	4.9	4.5	5.0	18.2
B3	4.3	4.8	4.7	4.5	18.3
B4	5.1	4.5	4.5	4.3	18.4
A TOTAL	17.2	18.9	17.9	20.2	74.2

Calculating the Sum of Squares of the interaction between Tillage Method and Soil Type

$$(AxB)SS = \sum_{i=1,j=1}^{n=16} \frac{(A_1B_1)^2 + \ \ldots\ldots\ldots\ldots\ldots + (A_4B_4)^2}{r} - CF$$

$$(AxB)SS = \sum \frac{[(4.0)^2 + (4.7)^2 + (4.2)^2 + \cdots + (4.3)^2]}{r} - 114.70$$

$$(AxB)SS = \sum \frac{[16 + 22.09 + 17.64 + \cdots + 18.49]}{3} - 114.70$$

$$(AxB)SS = \sum \frac{[248.23\ ]}{3} - 114.70$$

$$(AxB)SS = 116.42 - 114.70$$

$$(AxB)SS = 1.72$$

$$Error\ (z)\ Sum\ of\ Squares\ (E(z)SS) = TSS - (RSS + ASS + E(x)SS + BSS + (AxB)SS + E(y)SS$$

$$E(z)SS = 4.26 - (1.16 + 0.42 + 0.41 + 0.07 + 1.72 + 0.32)$$

$$E(z)SS = 4.26 - 4.1$$

$$E(z)SS = 0.16$$

7.5 Completing the ANOVA Table

Sources of Variation	df	Sum of Squares (SS)	Mean Sum of Squares (MSS)	Fcal
Replication	`r -1 = 3 – 1 = 2	1.16	$\frac{1.16}{2} = 0.58$	
Main factor - Tillage Method (A)	a -1 = 4-1 = 3	0.42	$\frac{0.42}{3} = 0.14$	$\frac{MSS(A)}{MSS(error\ x)} = \frac{0.14}{0.07} = 2$
Error (x)	(r-1)(a-1) = 2 x 3 = 6	0.41	$\frac{0.41}{6} = 0.07$	
Sub factor – Soil type (B)	b -1 = 4 -1 =3	0.07	$\frac{0.07}{3} = 0.02$	$\frac{MSS(A)}{MSS(errory)} = \frac{0.02}{0.53} = 0.04$
Error (y)	(r -1)(b -1) = (3-1)(4-1) =2 x 3 = 6	0.32	$\frac{0.32}{6} = 0.53$	
Interaction between – Tillage Method x Soil Type (A x B)	(a-1)(b-1) = (4-1)(4-1) = 3 x 3 = 9	1.72	$\frac{1.72}{9} = 0.19$	$\frac{MSS(A)}{MSS(error\ z)} = \frac{0.19}{0.01} = 19$
Error (z)	(r-1)(a-1)(b-1) =(3-1)(4-1)(4-1) = 2 x 3 x 3 = 18	0.16	$\frac{0.16}{18} = 0.01$	
Total	rab-1 = 48 -1 = 47	4.26		

Reading of the F-critical or tabulated values from the F- table at the various assigned levels of significance allowed.

For the case being considered, 1% and 5% levels of significance would be used.

F-critical table at 5% (0.05)

Critical values of F for the 0.05 significance level:

	1	2	3	4	5	6	7	8	9	10
1	161.45	199.50	215.71	224.58	230.16	233.99	236.77	238.88	240.54	241.88
2	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.39	19.40
3	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14
10	4.97	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98
11	4.84	3.98	3.59	3.36	3.20	3.10	3.01	2.95	2.90	2.85
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71	2.67
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49
17	4.45	3.59	3.20	2.97	2.81	2.70	2.61	2.55	2.49	2.45
18	4.41	3.56	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38

F-critical table at 1% (0.01)

Critical values of F for the 0.01 significance level:

	1	2	3	4	5	6	7	8	9	10
1	4052.19	4999.52	5403.34	5624.62	5763.65	5858.97	5928.33	5981.10	6022.50	6055.85
2	98.50	99.00	99.17	99.25	99.30	99.33	99.36	99.37	99.39	99.40
3	34.12	30.82	29.46	28.71	28.24	27.91	27.67	27.49	27.35	27.23
4	21.20	18.00	16.69	15.98	15.52	15.21	14.98	14.80	14.66	14.55
5	16.26	13.27	12.06	11.39	10.97	10.67	10.46	10.29	10.16	10.05
6	13.75	10.93	9.78	9.15	8.75	8.47	8.26	8.10	7.98	7.87
7	12.25	9.55	8.45	7.85	7.46	7.19	6.99	6.84	6.72	6.62
8	11.26	8.65	7.59	7.01	6.63	6.37	6.18	6.03	5.91	5.81
9	10.56	8.02	6.99	6.42	6.06	5.80	5.61	5.47	5.35	5.26
10	10.04	7.56	6.55	5.99	5.64	5.39	5.20	5.06	4.94	4.85
11	9.65	7.21	6.22	5.67	5.32	5.07	4.89	4.74	4.63	4.54
12	9.33	6.93	5.95	5.41	5.06	4.82	4.64	4.50	4.39	4.30
13	9.07	6.70	5.74	5.21	4.86	4.62	4.44	4.30	4.19	4.10
14	8.86	6.52	5.56	5.04	4.70	4.46	4.28	4.14	4.03	3.94
15	8.68	6.36	5.42	4.89	4.56	4.32	4.14	4.00	3.90	3.81
16	8.53	6.23	5.29	4.77	4.44	4.20	4.03	3.89	3.78	3.69
17	8.40	6.11	5.19	4.67	4.34	4.10	3.93	3.79	3.68	3.59
18	8.29	6.01	5.09	4.58	4.25	4.02	3.84	3.71	3.60	3.51
19	8.19	5.93	5.01	4.50	4.17	3.94	3.77	3.63	3.52	3.43

Note: The read values from the table have been highlighted to show how the F-critical values read from the F-table. The values are always read using the degree of freedom of a particular source of variation against the degree of freedom of a particular error.

Sources of Variations	Fcal	Fcrit (5%)	Fcrit (1%)
Main Plot Factor (A)	$\frac{0.14}{0.07} = 2$	df(3,6) = 4.76	df(3,6) = 9.78
Sub Plot Factor (B)	$\frac{0.02}{0.53} = 0.04$	df (3,6) = 4.76	df(3,6) = 9.78
Interactions (A x B)	$\frac{0.19}{0.01} = 1.16$	df (9,18) =2.46	df(9,18) = 3.60

7.6 Taking the Decision and Making the Conclusion

Main Plot Factor (Tillage Method):

$$Fcal\ (2) < Fcrit\ (\ df\ 3{,}6\ @\ 5\% = 4.76)$$

$$Fcal\ (2) < Fcrit\ (\ df\ 3{,}6\ @\ 1\% = 9.78)$$

Conclusion on Main Plot Factor (Soil Type):

There is no significance difference exists between the tillage methods (A) used in the experiment at both levels of significance. Thus the tillage methods are similar.

Subplot Factor or Second Factor (Soil Type):

$$Fcal\ (0.04) < Fcrit\ (\ df\ 3{,}6\ @\ 5\% = 4.76)$$

$$Fcal\ (0.04) < Fcrit\ (\ df\ 3{,}6\ @\ 1\% = 9.78)$$

Conclusion on Subplot (Soil Type)

No significant difference exists between the various soil types. Meaning the soil types did not differ statistically

Interactions (M x W):

$$Fcal\ (1.16) < Fcrit\ (\ df\ 9{,}18\ @\ 5\% = 2.46)$$

$$Fcal\ (1.16) < Fcrit\ (\ df\ 9{,}18\ @\ 1\% = 3.60)$$

Conclusion on Interactions (A x B)

There exists no significance difference. Hence one can conclude that the interactions between the main and sub factors did not differ statistically.

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