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# On-farm Trials for Farmers Using the Randomized Complete Block Design

by Phil Rzewnicki, Associate Extension Agriculturalist

Farmers are interested in evaluating new agricultural practices on their own farms. To produce results credible to themselves, other farmers, and researchers, a systematic method of testing should be used. If a comparison of agricultural practices results in one practice yielding a few more bushels of crop than another, this does not necessarily mean it is a more valuable practice. The difference may simply be due to field variation or chance.

Quantitative results can detect important differences between practices at a given level of probability. To do so, on-farm trials must incorporate two basic requirements in designing experiments: randomization and replication. Randomization ensures that there is no favoritism shown toward a practice being tested as the experiment is established. Replication reduces the risk that the results are due to chance alone. Randomization and replication are explained in more detail in NebGuide G84-723 "Maximizing the Use of Farm Strip Plots."

Farmers favor on-farm trials that use standard machinery and require little extra time. One on-farm trial method that has become acceptable to a large number of producers involves the use of long, narrow strip plots. The strip plots are arranged in a pattern called the randomized complete block (RCB) design. Calculations for analysis of the results can easily be done on a pocket calculator.

## The Design

Producers can readily use the RCB design with only a few limitations. No more than five items (treatments) should be tested in on-farm strip plots. Examples of treatments might include four soybean varieties, five rates of fertilizer, or three tillage methods. There should be five to seven repetitions (replications) of each treatment. A "block" is a grouping of a single occurrence of all treatments.

Figure 1 is an example of a field experiment using a RCB design for testing four weed control treatments labeled as A, B, C, and D. Five replications of each method are planned, thus, there are five blocks.

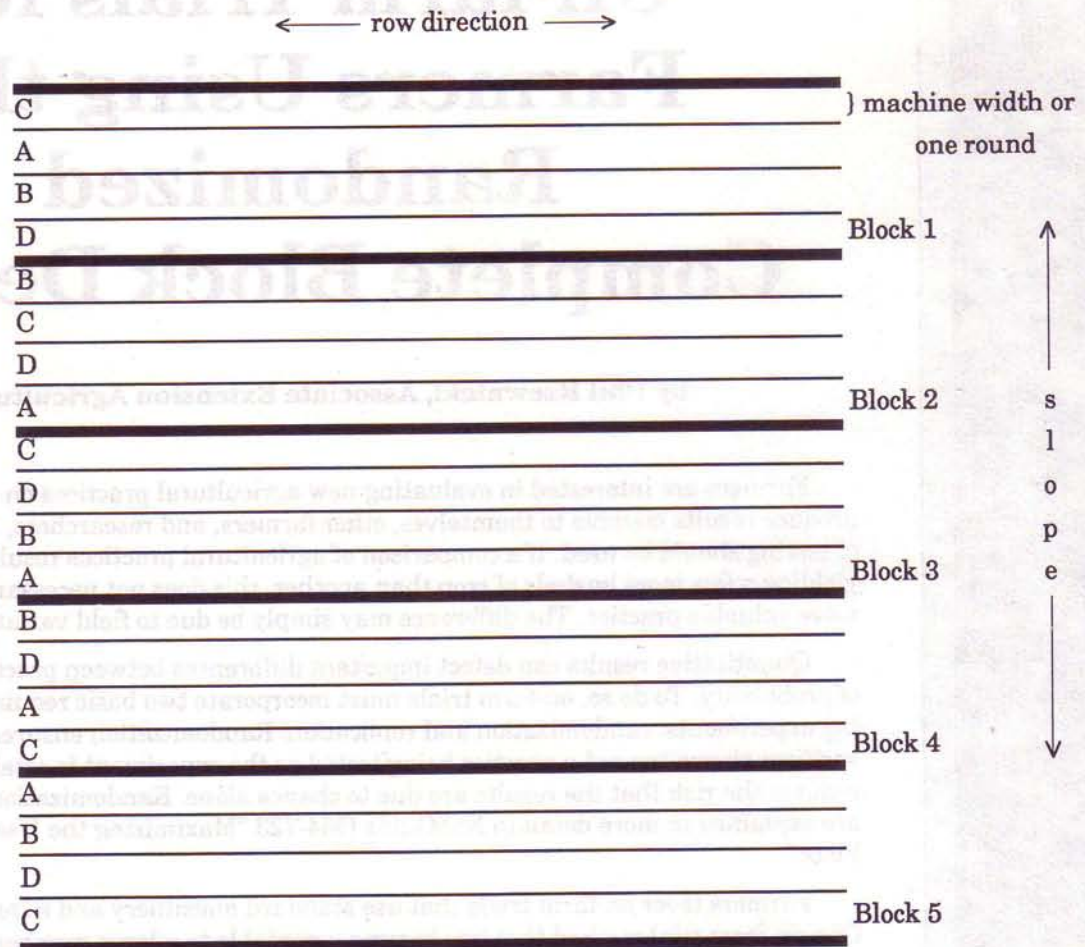


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**Figure 1. On-farm experiment of four treatments (A,B,C, and D) replicated five times using the randomized complete block design.**



The blocks are arranged to allow all treatments within a block to be exposed to similar conditions, such as slope, soil type and previous cropping history. Experiments conducted on a hillside should have the strips running perpendicular to the predominant slope of the test area or along the contours of the land. The blocks of strips will then account for much of the field variation due to differences in moisture and other factors that are affected by slope.

Within each block the treatments are randomly assigned to the strip plots. This randomization can be achieved by any chance selection method such as drawing numbers out of a hat. The strip plots can be the width (or two widths) of a producer's planting or harvesting equipment. In many cases this will be six or eight rows wide. Strip plot length can be anywhere from 100 feet to a half-mile. Experiments using half-mile long strips have been used with good experimental results.

All strips are managed identically through the growing season except for the treatments being tested. For example, if a trial is testing different methods of weed control, all strips should receive the same primary tillage, seedbed preparation, fertilizer application, insect control, etc. The only difference in management over the entire test area in this trial would be the weed control treatment used on each individual strip plot.



## Determining Yield Differences

The most common measure of performance in experiments with crops is yield (Other measures of performance may include seed weight, dropped ears, etc.). The strip plots must be individually measured for yield. Arrangements need to be made ahead of harvest to obtain a weigh wagon. Weigh wagons may be available from seed corn company representatives or agricultural researchers. Nearby weigh scales are another option for determining yield. Some producers add grain yield monitors to their combines. These can be used if their accuracy has been checked before harvesting the experiment plots.

Information on adjusting for grain moisture and calculating yields can be found in Extension Circular "Procedures for Field Demonstrations of Nitrogen Management Practices."

Proper statistical analysis of the yields requires the use of a procedure called the analysis of variance when there are three or more treatments in a trial. This analysis involves determining the sources of variation, degrees of freedom, and the amount of variation due to each source. When there are only two treatments, then a Least Significant Differences (LSD) comparison can be made without an analysis of variance procedure. (LSD calculations are covered in a later section.)

For the RCB design, the difference between the yield of any strip plot and the average yield of the entire test area is composed of variation from three sources:

- 1) field variation which is accounted for by the blocks,
- 2) the effects of the treatments, and
- 3) experimental error.

Degrees of freedom (d.f.) is a statistical term referring to the number of components less one which contribute to each source of variation. The d.f. associated with blocks in an experiment is one less than the total number of blocks. Likewise, the d.f. associated with treatments is one less than the number of treatments being tested. The d.f. for total variation in an RCB experiment is equal to one less than the total number of strip plots. To determine the d.f. associated with error, the blocks d.f. and the treatments d.f. are subtracted from the total variation d.f.

To find the amount of variation due to each source requires a number of squaring, adding and dividing calculations. This portion of the on-farm experiment is perhaps the most tedious. However, most calculators have these mathematical functions and careful use of them makes the process easier. (Calculations are made even easier with calculators or computers equipped with statistical functions). A term used for the variation due to each source is the "sum of the squares" or SS. Calculations for finding the SS for each source are simplified with the use of a "correction factor" or CF. It is equal to the square of the total of all the yields divided by the number of strip plots.

$$CF = \frac{(\text{Grand total})^2}{\text{Number of strip plots}} \quad [1]$$

**Table 1. Example corn yield data for sample calculations**

	Block					Trt Total	Trt Mean
	1	2	3	4	5		
Treatment A	103	101	102	106	107	519	103.8
Treatment B	99	105	103	107	99	513	102.6
Treatment C	114	115	110	107	112	558	111.6
Treatment D	105	110	103	105	115	538	107.6
<b>Block Total</b>	<b>421</b>	<b>431</b>	<b>418</b>	<b>425</b>	<b>433</b>	<b>2128</b>	<b>(Grand total)</b>



Table 1 contains imaginary corn yield data to provide example calculations. The example has the same number of treatments and blocks illustrated in Figure 1. The example is a trial comparing four methods of weed control using five replications of each method.

Following equation [1], the Correction Factor for the example would be:

$$CF = \frac{(\text{Grand total})^2}{\text{Number of strip plots}} = \frac{(2128)^2}{20} = 226,419$$

The next step in the analysis is to calculate the total variation or total SS. To do this, square each yield and then total the squared amounts. From this total, subtract the correction factor. Using the example weed trial to illustrate calculating the total SS:

$$\text{Total SS} = [A_1^2 + A_2^2 + A_3^2 + A_4^2 + A_5^2 + B_1^2 + B_2^2 + B_3^2 + \dots + C_1^2 + C_2^2 + \dots + D_4^2 + D_5^2] - CF \quad [2]$$

where  $A_1$  = yield in the first block of weed control treatment A,  
 $A_2$  = yield in the second block of weed control treatment A,  
 $\vdots$   
 $\vdots$   
 $B_1$  = yield in the first block of treatment B, etc.

$$\text{Total SS} = [103^2 + 101^2 + 102^2 + 106^2 + 107^2 + 99^2 + 105^2 + 103^2 + 107^2 + 99^2 + 114^2 + 115^2 + 110^2 + 107^2 + 112^2 + 105^2 + 110^2 + 103^2 + 105^2 + 115^2] - CF$$

$$\text{Total SS} = 226,882 - 226,419 = 463$$

The SS for variation accounted for by the blocks is found by totalling the yields in each block, squaring the totals, and adding the squared totals together. Divide the overall total by the number of treatments and then subtract the correction factor.

$$\text{Blocks SS} = \frac{\text{Block totals squared}}{\text{Number of treatments}} - CF \quad [3]$$

Following the weed control trial example:

$$\text{Block totals squared} = (A_1 + B_1 + C_1 + D_1)^2 + (A_2 + B_2 + C_2 + D_2)^2 + \dots + (A_5 + B_5 + C_5 + D_5)^2$$

$$\text{Blocks SS} = \frac{[421^2 + 431^2 + 418^2 + 425^2 + 433^2]}{4} - CF$$

$$\text{Blocks SS} = 226,460 - 226,419 = 41$$

The variation due to treatments is found by totalling the yields for each treatment, squaring these totals, and adding the squared totals. Divide the resulting total by the number of blocks and then subtract the correction factor.

$$\text{Treatments SS} = \frac{\text{Trt. totals squared}}{\text{Number of blocks}} - CF \quad [4]$$

Using the above weed control example:

$$\text{Trt. totals squared} = (A_1 + A_2 + A_3 + A_4 + A_5)^2 + (B_1 + \dots + B_3 + \dots + B_5)^2 + (C_1 + \dots + C_5)^2 + (D_1 + \dots + D_5)^2$$

$$\text{Treatments SS} = \frac{[519^2 + 513^2 + 558^2 + 538^2]}{5} - CF$$

$$\text{Treatments SS} = 226,668 - 226,419 = 249$$



The most difficult of the calculations are now complete. Error SS can easily be determined by the following:

$$\text{Error SS} = \text{Total SS} - \text{Blocks SS} - \text{Treatments SS} \quad [5]$$

For the example experiment:

$$\text{Error SS} = [463 - 41 - 249] = 173$$

A statistical value can now be used to indicate whether or not the treatments in an on-farm trial are significantly different from each other. Called the "F" test in honor of a famous statistician, R.A. Fisher, this value is the ratio of one mean square to another. A mean square (MS) is a sum of squares or SS divided by its corresponding degrees of freedom. The ratio of the mean square for treatments over the mean square for error is used as a test for significant differences among the agricultural practices being compared. It can be called the "Observed" F.

**Table 2. Values of Expected F at 5% probability level.**

		Degrees of freedom for treatments			
		1	2	3	4
Degrees of freedom for error	5	6.61	5.79	5.41	5.19
	6	5.99	5.14	4.76	4.53
	7	5.59	4.74	4.35	4.12
	8	5.32	4.46	4.07	3.84
	9	5.12	4.26	3.86	3.63
	10	4.96	4.10	3.71	3.48
	11	4.84	3.98	3.59	3.36
	12	4.75	3.89	3.49	3.26
	13	4.67	3.81	3.41	3.18
	14	4.60	3.74	3.34	3.11
	15	4.54	3.68	3.29	3.06
	16	4.49	3.63	3.24	3.01
	17	4.45	3.59	3.20	2.96
	18	4.41	3.55	3.16	2.93
	19	4.38	3.52	3.13	2.90
	20	4.35	3.49	3.10	2.87
	21	4.32	3.47	3.07	2.84
	22	4.30	3.44	3.05	2.82
	23	4.28	3.42	3.03	2.80
	24	4.26	3.40	3.01	2.78

$$\text{Observed F} = \frac{\text{Treatments MS}}{\text{Error MS}} = \frac{(\text{Treatments SS} / \text{Treatments d.f.})}{(\text{Error SS} / \text{Error d.f.})} \quad [6]$$

Observed F values are compared to Expected F values to decide whether or not there are significant differences among treatments. Table 2 is a listing of Expected F values for the 5 percent probability level. The 5 percent level is the most commonly used test level in field crop research. Values for other probability levels can be found in most standard books on statistics. (A probability level is the level of risk one is willing to take to declare treatment differences exist even if an infinite number of samples could be taken and no true differences were found.)



The Expected F value is found along the top of the table by the treatments d.f. and along the side of the table by the error d.f. One note of caution is that there is little value in performing experiments with less than 5 d.f. for error due to a large loss in precision. As sample size increases, the ability to detect smaller differences between treatment means increases. Scientific investigators in critical experiments strive to obtain at least 20 d.f. for error. In on-farm applied research comparing a few treatments using long, narrow strip plots in 5 to 7 blocks, an on-farm trial should be able to detect yield differences important to the producer even if less than 20 d.f. for error are not obtained.

If the Observed F is larger than the Expected F, treatment averages are significantly different from each other at the 5 percent probability level. This indicates that there is less than a 5 percent or 1 in 20 chance that the treatment averages could vary as much as they do by chance alone. In other words, one can be reasonably sure that the different agricultural practices being tested are causing differences in yields.

If the Observed F is less than the Expected F, we can conclude that the analysis of the experiment results detected no significant differences among the treatments at the 5 percent probability level. If this is the case, the analysis of yield differences is complete.

Analyzing the weed control experiment for significant treatment differences:

Degrees of Freedom:    Total d.f. = 20 - 1 = 19  
                                      Blocks d.f. = 5 - 1 = 4  
                                      Treatments d.f. = 4 - 1 = 3  
                                      Error d.f. = (19 - 4 - 3) = 12

$$\text{Observed F} = \frac{\text{Treatments MS}}{\text{Error MS}} = \frac{(\text{Treatments SS} / \text{Treatments d.f.})}{(\text{Error SS} / \text{Error d.f.})}$$

$$\text{Observed F} = \frac{249/3}{173/12} = \frac{83.0}{14.4} = 5.76$$

From Table 2, the Expected F for Treatments d.f. of 3 and Error d.f. of 12 at the 5 percent level of significance is equal to 3.49. Since the Observed F of 5.76 is greater than the Expected F, we can conclude that corn yields for the treatments were significantly different with less than a 5 percent probability that they are actually equal and a wrong conclusion has been made.

## Separating Treatment Differences

After an Observed F is found to be larger than the Expected F, the final task is to determine which of the treatment averages are significantly different from each other. A statistical test called the Least Significant Difference or LSD can be used. This same test is used for an experiment comparing only two treatments. Calculation of the LSD involves the use of a "t" value from Table 3 and values that were previously calculated.

The t value needed is found along the side of the table by the error d.f. of the experiment. (In the case of experiments with only two treatments, equations 1 through 5 can be used to calculate error MS. The F Test is not needed.) To calculate the LSD, the t value is multiplied by the square root of twice the error mean square divided by the number of blocks.

$$\text{LSD} = t \times \sqrt{\frac{2 \times \text{Error MS}}{\text{Number of blocks}}}$$

[7]



**Table 3. Values of t for 5% probability level.**

Degrees of freedom for error	t
5	2.571
6	2.447
7	2.365
8	2.306
9	2.262
10	2.228
11	2.201
12	2.179
13	2.160
14	2.145
15	2.131
16	2.120
17	2.110
18	2.101
19	2.093
20	2.086
21	2.080
22	2.074
23	2.069
24	2.064

When the difference between two treatment averages is greater than the LSD, the means are considered significantly different at the 5 percent probability level. The odds are less than 1 in 20 that the two agricultural practices are different by chance alone. For any two means whose difference is less than the LSD, the two treatments would have to be considered equivalent in performance.

Determining which treatments are significantly different in the weed control example:

From Table 3, the t value for the example error d.f. of 12 at the 5 percent probability level is 2.179. The least significant difference or LSD between treatment means is:

$$\text{LSD} = t \times \sqrt{\frac{2 \times \text{Error MS}}{\text{Number of blocks}}} = 2.179 \times \sqrt{\frac{2 \times 14.4}{5}} = 5.23$$

In the example, weed control method C is significantly different from methods A and B at a 5% level of probability since (111.6 - 103.9) and (111.6 - 102.6) are larger than 5.23. This means the odds are less than 1 in 20 that method C is different from A and B by chance alone. However, it cannot be said that method C is significantly different from method D. The difference between the means of C and D is less than the LSD. For the on-farm test conducted, weed controls C and D appear to be equivalent in performance.

## Miscellaneous Considerations

**Contours** - From Figure 1 you may think that only straight, rectangular strip plots can be used for on-farm experiments. In many cases, the total testing area will require 10 to 12 acres making it difficult to find a uniform field. Strip plots that follow contours or are gradually curved can be used. If yields are measured without a grain yield monitor, the land area of each curving plot needs to be estimated.

**Middle Row Harvesting** - Experiments involving treatments that may overlap onto or affect adjacent strips should have yields based on the middle rows of the strip plots. Com-



parisons of broadcasted fertilizer liquids or any sprayed applications will be more precise if the outer rows are avoided when measuring yields. For example, it may be desirable to harvest only the center four rows of adjacent eight row strip plots when overlap of the applied treatments is likely. Doing so also leaves four row strips of border rows which can be harvested after yields for the center rows are recorded.

*Economic Comparisons* - Differences in costs of agricultural treatments being tested may influence the decision of a producer to use a particular practice even if its average yield was significantly lower than another practice. The LSD can be useful in analyzing cost differences. For example: An on-farm trial using corn yields as the measure of performance resulted in an LSD of 9.0 bushels per acre. Current market price for corn was \$2.50. This would indicate there had to be a cost savings of  $(9.0 \times \$2.50)$  or \$22.50 or more for a significantly lower yielding treatment to remain competitive with a higher yielding choice.

*When Interruptions Occur* - Whenever any activity over the test area such as spraying, cultivating or harvesting is delayed by weather or nightfall, it is best to complete that activity over an entire block. When the activity is resumed for the rest of the test area, variation due to the interruption will be confined to block differences, thus keeping experimental error to a minimum.

*Measure of Precision* - The likelihood of finding significant differences between treatments decreases as experimental error increases. A measure of how well experimental error was controlled is called the Coefficient of Variation or CV. It is the ratio of the error mean square over the overall average yield.

$$CV = \frac{\text{Error MS}}{\text{Total of yields / Number of strip plots}} \times 100 \quad [8]$$

Field crop experiments that achieve coefficients of variation less than about 15% would be considered credible by most agricultural researchers.



## On-farm Trial Calculation Worksheet

**DATA TABLE**

	B l o c k							Trt Total	Trt Mean
	1	2	3	4	5	6	7		
Trt A									
Trt B									
Trt C									
Trt D									
Trt E									
Block Total									(Grand total)

CF = (Grand total)<sup>2</sup>/No. of strip plots

CF = (Grand total)<sup>2</sup>/(No. treatments x No. blocks)

CF = ( )<sup>2</sup>/ =

Total SS = [A<sub>1</sub><sup>2</sup>+A<sub>2</sub><sup>2</sup>+A<sub>3</sub><sup>2</sup>+....+B<sub>1</sub><sup>2</sup>+....+C<sub>1</sub><sup>2</sup>+....+D<sub>1</sub><sup>2</sup>+....+E<sub>6</sub><sup>2</sup>+E<sub>7</sub><sup>2</sup>] - CF

Total SS = [ ] -

Blocks SS = [(Blk 1 total<sup>2</sup>+Blk 2 total<sup>2</sup>+Blk 3 total<sup>2</sup>+....)/No. treatments] - CF

Blocks SS = [( )/ ] -

Blocks SS =

Treatments SS = [(Trt A total<sup>2</sup>+Trt B total<sup>2</sup>+Trt C total<sup>2</sup>+....)/No. blocks] - CF

Treatments SS = [( )/ ] -

Treatments SS =

Error SS = Total SS - Blocks SS - Treatments SS

Error SS = - - =

Degrees of freedom (d.f.):

Total d.f. = No. of strip plots - 1 =

Blocks d.f. = No. of blocks - 1 =

Treatments d.f. = No. of treatments - 1 =

Error d.f. = Total d.f. - Blocks d.f. - Treatments d.f. =

Treatments MS = Treatments SS / Treatments d.f

Treatments MS = / =

Error MS = Error SS / Error d.f.

Error MS = / =



**If experiment has three or more treatments, proceed with F Test:**

Observed F = Treatments MS / Error MS

Observed F = \_\_\_\_\_ / \_\_\_\_\_ = \_\_\_\_\_

From Table 2, Expected F for Treatments d.f. \_\_\_\_\_

and Error d.f. \_\_\_\_\_ is equal to \_\_\_\_\_

If the calculated Observed F is less than the Expected F, then "there are no significant differences among the treatments at the 5% probability level."

**If the Observed F is greater than the Expected F or there are only two treatments in the trial, proceed with Least Significant Difference (LSD) Test:**

t from Table 3 at Error d.f. \_\_\_\_\_ is equal to \_\_\_\_\_

$LSD = t \times \sqrt{(2 \times \text{Error MS}) / \text{No. of blocks}}$

LSD = \_\_\_\_\_  $\times \sqrt{(2 \times \text{_____}) / \text{_____}}$

LSD = \_\_\_\_\_

**Treatment Means Differences (Note: Ignore negative values):**

Trt A Mean - Trt B Mean = \_\_\_\_\_

Trt A Mean - Trt C Mean = \_\_\_\_\_

Trt A Mean - Trt D Mean = \_\_\_\_\_

Trt A Mean - Trt E Mean = \_\_\_\_\_

Trt B Mean - Trt C Mean = \_\_\_\_\_

Trt B Mean - Trt D Mean = \_\_\_\_\_

Trt B Mean - Trt E Mean = \_\_\_\_\_

Trt C Mean - Trt D Mean = \_\_\_\_\_

Trt C Mean - Trt E Mean = \_\_\_\_\_

Trt D Mean - Trt E Mean = \_\_\_\_\_

Treatment differences greater than the calculated LSD indicate the treatments that are significantly different at a 5% probability level.