On-Farm Research Guidebook

by Dan Anderson

WHAT IS RESEARCH?

Farmers have an abundance of ideas. Sometimes the ideas (and the new practices and products that may accompany them) can be implemented quickly and easily. At other times, a major investment is necessary. But no matter how simple or complex an idea, a certain amount of risk is involved. To minimize your risk, it's smart to test these ideas on a small scale first. And that's what research really is: testing ideas to determine whether they're good or bad.

Many of you are in transition from conventional farming to more sustainable practices. This process can be a long one, and questions may arise that have never been asked before. Properly conducted participatory on-farm research (research initiated and conducted by farmers on their farms) gives you a more active role in the exchange of agronomic information.

This guide is a resource for farmers interested in participatory on-farm research. In the following sections, I will explain basic research principles and provide easy-to-use guidelines for conducting simple on-farm experiments.

YOUR RESPONSIBILITY

When you conduct a trial on your farm, you are in a very real sense a researcher. This title of researcher carries a certain level of responsibility. Even if the results will never be published and apply only to you, your trials yield objective and accurate information on which you safely can base future decisions. For this reason, you must ensure that the information derived from your study is reliable and true.

Conducting research that produces reliable and true information requires discipline; tied in with discipline is the concept of *rigor*. Rigorous research is research conducted in accordance with strict controls and principles—which means discipline on your part. On-farm research can be adequately rigorous, but certain statistical principles must be maintained. Otherwise the information you obtain could be meaningless or, worse yet, deceptive. The basic statistical principles you'll need for your research will be covered in the "Analysis" section.

The success of your research trial will depend initially on how well it's planned. Even a simple research project takes time to plan, so don't underestimate this stage of the project. With adequate time and energy invested in planning and preparation, research can be an exciting and valuable activity.

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Sampling and Replication

How well a population can be represented by a sample depends on the sample size. The larger the sample size, the better it will represent the population. Say you're researching a population of 1,000 individuals. Would you trust one of those individuals, chosen at random, to provide an accurate, representative measurement of the entire population? Chances are that the individual would not accurately represent the population. What if your sample contained ten individuals randomly chosen from the population? That would be better than the sample of one, but not as good as a sample of 100. As the sample size approaches the size of the population, the sample will be an increasingly better representation of the population. The only way to get completely accurate results is to measure every individual in a population.

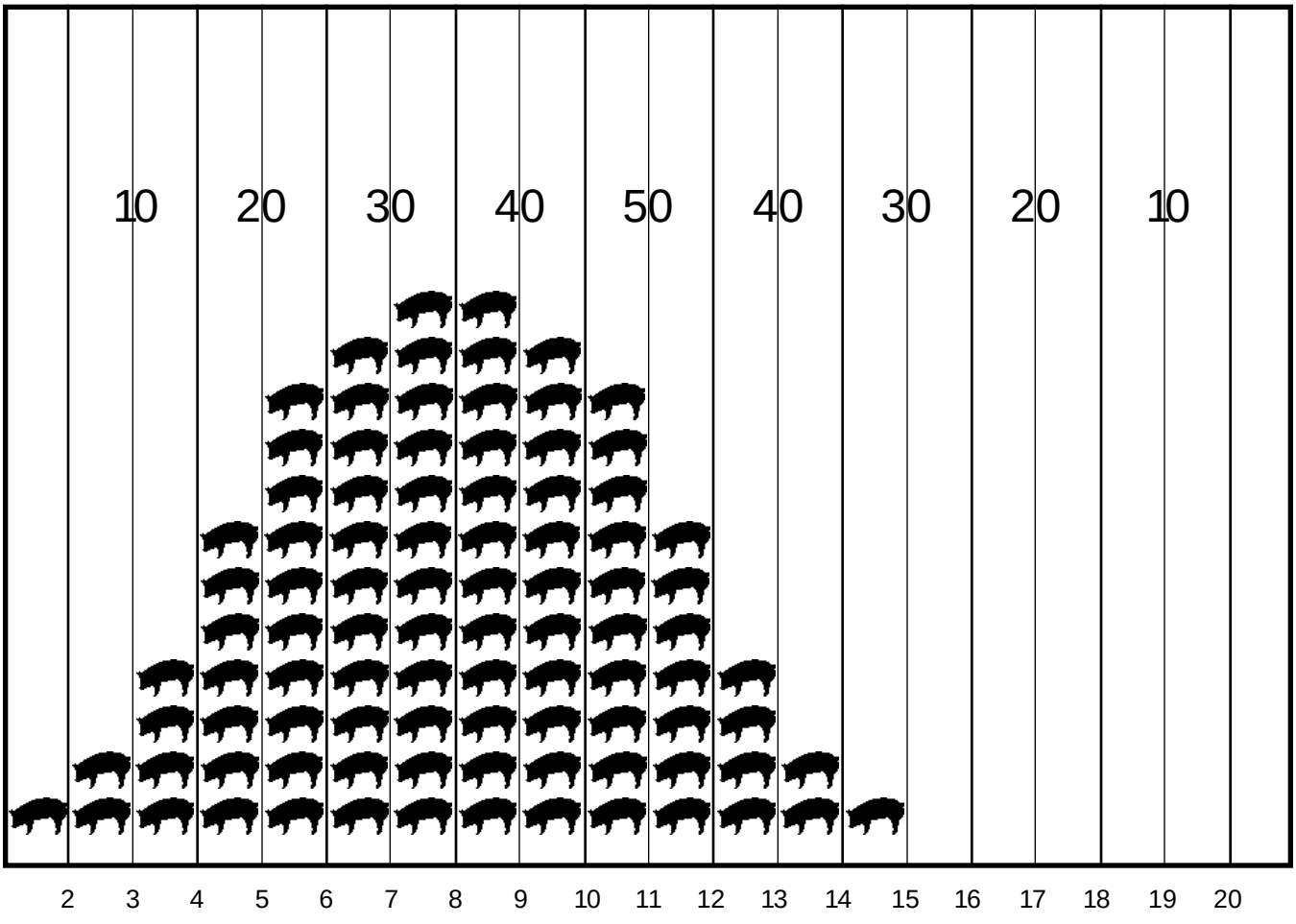
The point is that each treatment you compare in an experiment needs to be done more than once. That repetition is called *replication*. Any sample size greater than one is considered to be replicated. In field research, replication means putting out more than one plot of each treatment. The more replications you make, the easier it will be to detect small but potentially important differences between the treatments you're comparing.

How many replications (also called reps) are enough? Six is a good minimum number of reps for field experiments when two treatments are compared using the design discussed in the upcoming "Step-By-Step Guide" section. The precision you gain by having more than six reps is usually not worth the extra expense.

Sampling and Randomization

The best method for sampling a population is *randomization*. Samples should be chosen in such a way that each possible sample has an equal chance of being chosen. Dice are a good example. When dice are tumbled in the hand and then thrown out on a table or game board, players assume that there is an equal chance of any of the possible numbers (one through six) turning up. If you made 6,000

Figure 1. A frequency distribution of sows according to average litter size.



throws with a balanced die and kept track of the numbers, each number (one through six) would turn up about 1,000 times. If the die is loaded (one side heavier than the other), the throws are no longer random because a bias has been introduced that favors one number over the others.

In field experiments, plots are considered samples and are organized in the field in such a way that each plot has the same chance of occurring in any location. This randomization hopefully eliminates any biases in the field. A method for randomizing plots in your field will be explained a little later.

Normal Distribution

Much of the mathematics of statistics is based on what's called the *normal distribution.* The normal distribution can be illustrated with an example. Let's say that for some strange reason you collected all the White Yorkshire sows that are alive and producing litters in 1993 in Champaign County. Say the sows are gathered in Memorial Stadium at the University of Illinois. You stand down at the five-yard line of the football field and ask for all the sows with a lifetime average litter size between one and two to join you on the field. One sow comes down from the seats and stands between the five- and ten-yard lines. Next you move over to the ten-yard line and call for sows with an average litter size between two and three to come onto the field. Two sows line up between the ten- and fifteen-yard lines. You continue in this manner, increasing the litter size in increments of one for every five yards on the football field. After all the sows are on the field, the scene from the top stands might look something like Figure 1.

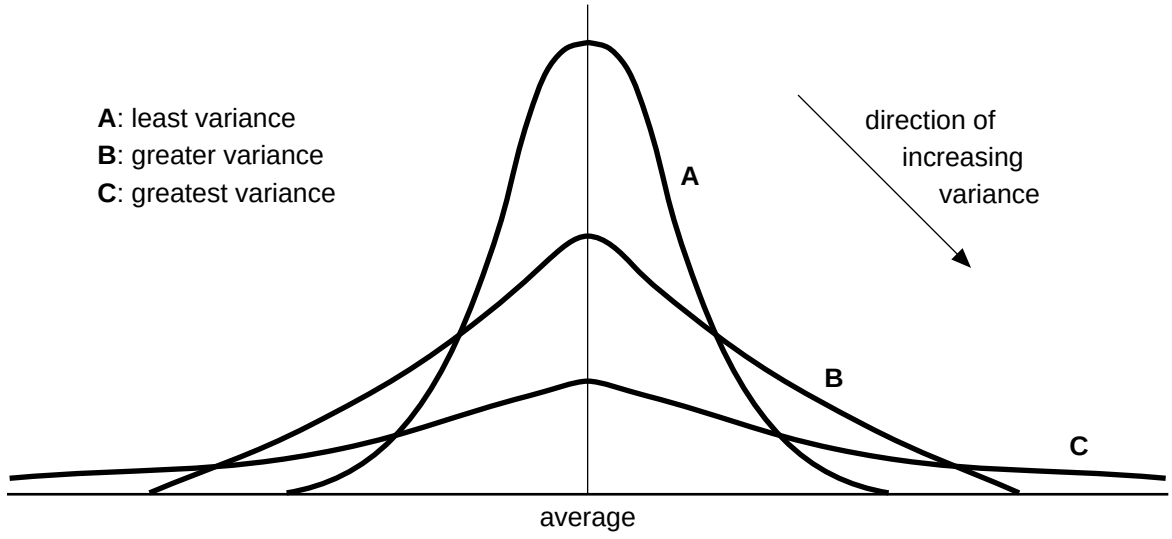
If you chalked a line around the outside of our neatly assembled sows, it would be easy to see that the organization of the sows according to litter size forms the shape of a bell. This bell-shaped curve contains what is referred to as the *frequency distribution*. A frequency distribution that is shaped like a bell is called a normal distribution. In many situations, this normal curve describes the frequency of events or characteristics that occur in populations.

Notice the small number of White Yorkshire sows that produced extremely small or extremely large average litter sizes. Their occurrence is rare, and therefore they are located on the outer edges of the curve. The majority of sows are grouped around the middle because their occurrence is common. The average litter size for all the sows is eight pigs per litter. You can see that this value occurs at the middle of the bell where the curve hits its highest point. It is this *average* that will be used for comparison of treatments in on-farm research.

Variation

Another thing to notice about the bell curve is the range of average litter sizes. Litter sizes vary within the population from one to fifteen. Why don't all the sows within this particular population produce litters of the same size? In other words, why is there variation within a population? Variation is due to many factors (genetic, environmental, managerial, and so forth) acting upon individuals within a particular population. Some of these factors are obvious and can be accounted for; others cannot. In a real-life situa-

Figure 2. The effect of variance of the normal distribution curve.



A, B, and C are three populations with the same average, but with different variances.

tion, no one would expect every sow of the same breed, within the same county, or even on the same farm to produce exactly the same litter size. In statistical terms, the measure of this naturally occurring difference is called the *variance*.

The variance is described by how wide the bell-shaped curve spreads and is a measure of how far from the average the population can go. The variance is a small number when the population is grouped tightly about the average and a large number when the population spreads widely (see Figure 2). When you compare two or more treatments, simple averages are not enough; you'll need to know if the differences are due to the treatments or to natural variation. That's why knowing the variance is so important.

If the differences are due to the treatments, they are considered "real" or significant differences. If the differences are due to natural variation, they are not truly differences and are considered "not real" or not significant.

The Three Rs

Keep in mind the three Rs of research: Replicate, Randomize, and Request help. Even professional researchers seek the advice of statisticians at any or all stages of the research process. If you're not sure about anything, seek help. Better to take a few minutes to make sure you're doing something correctly than to find out later that it was done wrong and the extra time and energy you spent were all for nothing.

This section breaks the research process down into steps you can follow in conjunction with the worksheets provided in the appendix. Directly below is a quick-access list of the steps. After you've gone through the process a few times, the quick list can be used as a reminder.

1) Ask a question (see Worksheet A-1)
2) Draw a diagram of the plot plan (see Worksheet A-2)
3) Choose the field and location
4) Measure off the field
5) Apply the treatments
6) Collect the data (see Worksheet A-3) and harvest plots (see Worksheet A-4)
7) Analyze the data (see Analysis Worksheet)
8) Draw inferences

1) Ask a question (see Worksheet A-1)

Remember, the question is where it all starts. Narrow your idea or inquiry down to its simplest form — a researchable comparison. For example: ridge-till versus current tillage system, 100% nitrogen rate versus 75% nitrogen rate, or soil-health additive versus no soil-health additive.

If you're having trouble boiling down your thoughts, talk to others to help clarify your objectives. No matter what your question is, keep it simple, especially at first. The more simple a research project is, the easier it is to conduct.

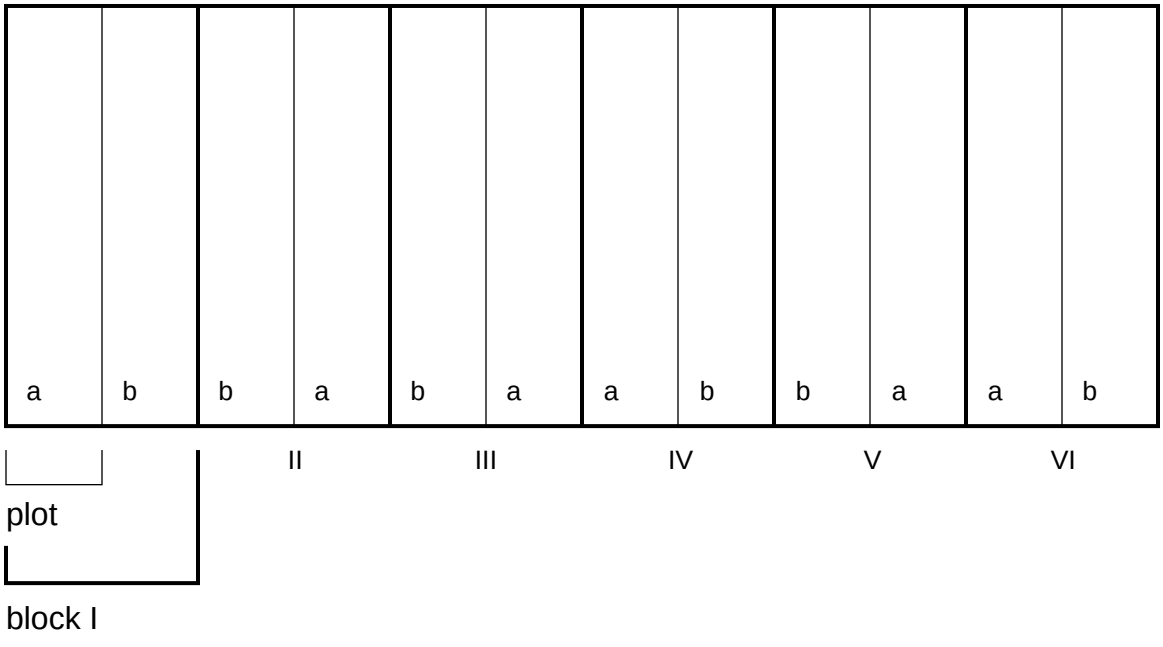
2) Draw a diagram of the plot plan (see Worksheet A-2)

First, consider *size*. Draw out the plot plan of your experiment. The plots should all be the same size (the same width and the same length). Plot width is determined by equipment size and is generally one round. The length of your plots is determined by the length of the field to avoid having to turn around in the middle of the field. Smaller plots will contain less natural variation.

Next comes *design*. A common and easy-to-use experimental design for on-farm research is the randomized complete block (see Figure 3). It is useful in accounting for and filtering out variation in agricultural soils. Each block contains one set of all the treatments being compared. The treatments are randomized within the blocks. Each block represents one replication.

Lastly, be sure you *randomize*. If you compare only two treatments, a coin toss can determine the random order of the plots within blocks. Start with a blank plot plan (see Worksheet A-2) and a coin. Flip the coin (heads for treatment a and tails for treatment b) and assign the treatments to the plots.

Figure 3. Randomized complete block design with two treatments (a and b) repeated six times (blocks I-VI).



If there are more than two treatments, label separate pieces of paper (a, b, c, and so on until you've covered all the treatments), fold the sheets, and put them in a bucket. Shake the bucket to mix up the paper and draw out one of the sheets. The drawn treatment is assigned to the first plot in the first block. Do not return the sheet; shake the remaining papers and draw again. This treatment is assigned to the second plot in the block. When treatments are assigned to all the plots in the first block, return the pieces of paper to the bucket and repeat the process for the next block.

3) Choose the field and location

There are several things to consider when choosing a field for your experiment. Ideally, it should be uniform in slope, drainage, and fertility, and of a soil type that is representative of the farm. The total width of the experiment should be calculated using Formula 1, and the chosen field should be large enough to accommodate the whole experiment.

Formula 1.
[row width (inches) x row number (per plot) x number of plots]/12 = total width (in feet)

Does the field have a slope? Orient the plots so that they run vertically up and down the slope. The plots will be more uniform than if they are laid out across the slope. Also, with the latter orientation, the treatments higher on the slope may wash downhill into the plots below. Figure 4 illustrates the right and wrong ways to orient the plots.

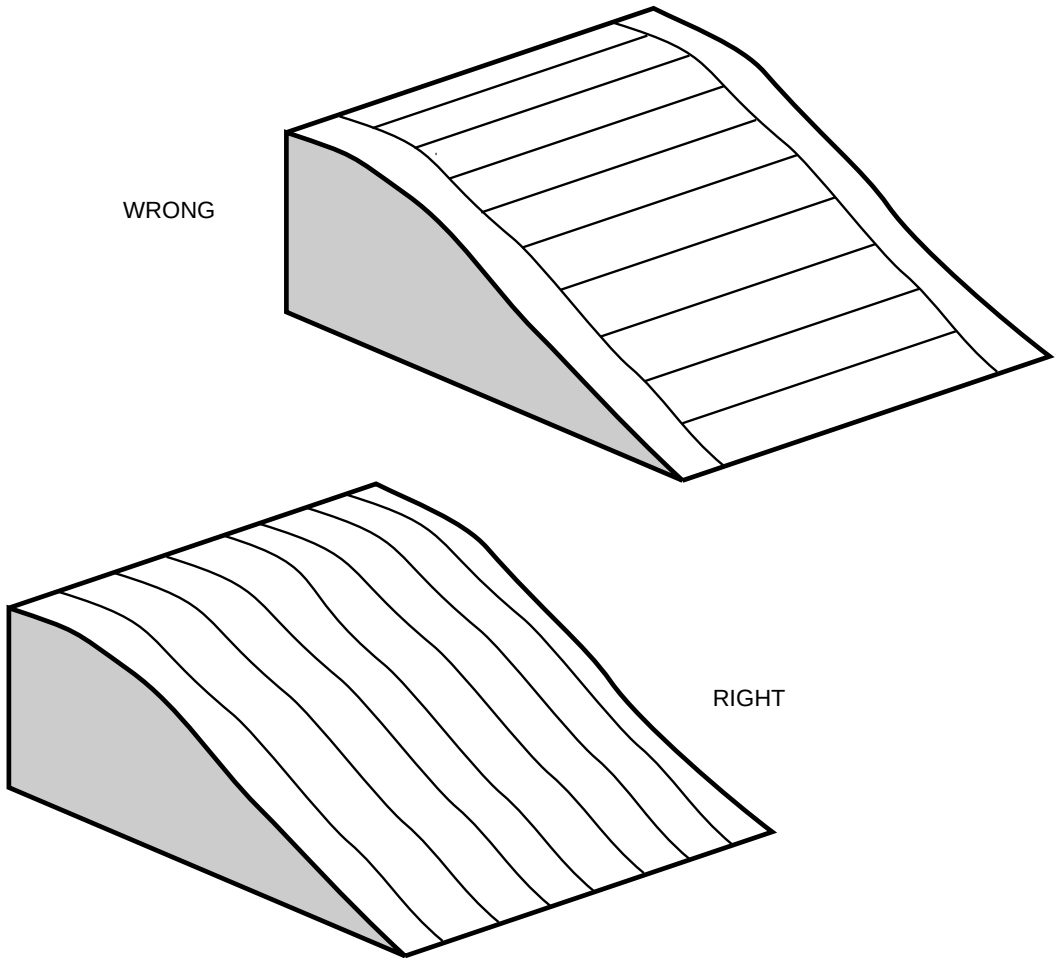
4) Measure off the field

After doing the plot plan on paper, take the plan, a tape measure, and a handful of flags to the field and mark out the plots. Mark each plot with a labeled stake that can be read without getting off the tractor.

5) Apply the treatments

There are some things you should consider before you apply your treatments. Your experiment is

Figure 4. Plot orientation on slope.



designed to compare the effects that different treatments have on a particular measure such as yield. Therefore, you want to be sure that the differences measured are due to the treatments, not some other factor. Apart from the intentional variation created by the treatments, the plots should be as identical as possible. Uniform plots will minimize natural variation and isolate any measured differences so they can be attributed directly to the treatments. Some practices that will keep your plots uniform are to drive over all the plots the same number of times; till all the plots in the same way; and control weeds in the same way in all plots.

What you do is important; so is *how* you do it. As much as possible, standardize the techniques by which the field work is done: For example, if different rates of a treatment are being tested, set the equipment to apply the first rate and do all the reps of that rate, then change the setting and do all the reps of the second rate, and so on.

6) Collect the data (see Worksheet A-3) and harvest plots (see Worksheet A-4)

The purpose of each experiment will affect the measurements taken before, during, and after the growing season. Keep your question continually at the forefront of your mind so that the information being collected will help to answer the question.

Examples of different measurements are periodic soil samples, weed counts, whole-plant wet weights, whole-plant dry weights, insect counts, earthworm counts, percentage of residue cover, soil temperature, and plant heights.

Although data collection sounds complicated, it's really just observation, something that every farmer does naturally every day. Recording your observations is vital to research. If you always carry a pencil and small notebook, you can easily jot down observations and ideas and record the date as you write. Be sure to note from which plots the observations were taken. Additional useful observations are weather, weed types and pressure, insect and other pest damage, soil condition, dates of operations, things that went wrong, diseases, chemicals applied, if more than one person worked on the plots, and who worked on which plots.

If more than one person collects the data, everyone involved should use the same technique. Uniformity of technique reduces the human factor as a source of variation. For pre-planned measurements such as plant heights and harvest, it may be easier to use a worksheet (see Worksheet A-3).

Special tools and equipment or the services of a laboratory may be needed for some types of measurements. If this is the case, seek help from professionals and make the necessary arrangements at the planning stage.

If you consider what you want to measure and the time you have available, you can decide on the best times for data collection and use a calendar to help schedule your time most efficiently.

Yield is usually the most important measurement of an on-farm experiment. You need several pieces of information to calculate the plot yields: harvest weight, percent moisture, length of harvest rows, row width, and number of rows harvested. Using this information, you can calculate the bushels per acre yield using the harvest calculation worksheet (Worksheet A-4 in the appendix).

Please remember: Each plot must be weighed separately!

7) Analyze the data (see Analysis Worksheet)

You've collected a list of numbers and you want to know what they mean. This is where statistics comes in handy. The following steps will work when you compare two different treatments. If you have more than two treatments, you can use the following procedure and just compare two at a time (a to b, b to c, a to c, etc.). There are other ways to do the same job, but it is beyond the scope of this guide to explain them.

If you have a calculator that does square roots, you should have no problem going through the calculations. If you do not want to do the math, or if your experimental design is beyond what can be handled by a simple t-test, you can send your data to the on-farm research coordinator at the University of Illinois for analysis.

7-1) Fill in the table on the Analysis Worksheet

List your data (for example, the yields of each block) in columns A and B under the "Treatments" heading of the table on the Analysis Worksheet (in the appendix). The remainder of the table is self-explanatory. Table 1 on the next page shows what the table looks like before it is filled out. The final product of the worksheet table is the sum of squares, the number in the box labeled D^2_{tot}.

7-2) Calculate the variance.

Divide the sum of squares by one less than the number of repetitions. (Reps, also called blocks, will appear as "r" in the equation.) This figure is the variance of the differences and will be referred to as *variance.*

$$\text{variance} = D^2_{tot}/(r-1)$$

Table 1. Sum of squares calculation.

	Treatments		Difference (C)	Deviation (D)	Deviation squared (D^2)
Blocks (r)	A	B	C = (A - B)	$D = C - C_{avg}$	$D^2 = D \times D$
I					
II					
III					
IV					
V					
VI					
Totals					D^2_{tot} =
Averages	A_{avg} =	B_{avg} =	C_{avg} =		

The averages (A_{avg}, B_{avg}, and C_{avg}) are calculated by dividing the totals by the number of blocks (r), with the total divided by r equalling the average.
D^2_{tot} symbolizes the total of the squared deviations. To calculate D^2_{tot} add together all the numbers in the D^2 column.

7-3) Calculate the variance of the means.

Divide the variance by the full number of reps. This result is the variance of the means.

variance of the means = variance/r

7-4) Calculate the standard error.

Take the square root of the variance of the means. This figure is the standard error of the means.

standard error = square root of the variance of the means

7-5) Calculate the least significant difference (LSD).

Take the answer from step 7-4 and multiply it by the appropriate t-value.

Standard error × t-value = LSD

The T-value. There is always a chance that the differences between the treatments will be misread. The *t-value* accounts for the probability of committing an error.

In research, there are two main types of errors that can be made. A difference can be declared when in reality none exists. This is referred to as a type I error, the probability of which is represented by alpha or α (see Table 2). The second type of error, type II, has a probability of beta (β). A type II error is committed when no difference is declared when in fact a difference exists. The alpha level chosen by the researcher determines the probability of committing a type I error. For example, if significant differences are accepted at an alpha level of α=.10, then the researcher is willing to risk a one-in-ten chance of making a type I error. For field experiments, an alpha level of α=0.05 is often considered acceptable. If a difference occurs at this level, there is still a one-in-twenty chance that the difference only occurred because of natural variation and is not real.

The possibility of a Type II error, beta, goes up as alpha goes down. Weighing the consequences of the two error types can help you manage the risks. In some cases, making one type of error might be acceptable, but the other type of error could cost you a lot of money down the road.

For example, say you're comparing the yields of two corn varieties. The consequences of making a type I error (declaring a difference when none exists) would not be that serious. The cost of such an error would be equal to the difference in the price of the seed. If a type II error is committed (declaring no difference when one really does exist), it would mean the loss of the yield difference of the two varieties. Depending on how big the difference is, such a loss could be substantial. Type II errors typically have been ignored, and researchers have worked hard to reduce their alpha. Thus, many type II errors have been made and real differences have been ignored.

To lower beta, alpha must be raised. An alpha level of α =.30 brings the beta down to an acceptable level. The correct alpha level is up to the researcher. It all depends on risk and consequences.

7-6) Look for a significant difference.

Take the answer from step 7-5, the LSD, and compare it to the box from the Analysis Worksheet table labeled C_{avg}. If your C_{avg} is a negative value, drop the negative sign. If the C_{avg} value is larger than the LSD, the two treatments are significantly different. If the C_{avg} value is less than the LSD, the two treatments are not significantly different.

8) Draw inferences

Discuss the results of your data with others. If your results seem to be out in left field, review your notes for a possible explanation. How was the rainfall for the year? Did something go wrong when you applied the treatments? Sometimes no plausible explanation will exist.

Even if the data looks good and you feel confident about the results, it is wise to repeat the study a second and even third year before you base a large-scale change on the results. Weather and environment are rarely the same from year to year, and different environments are a source of variation within the population of treatments being compared. You'll want to know how the population reacts under fluctuating yearly conditions because this is an important aspect of producing information that is reliable and true.

Table 2. T-values at three different alpha (α) levels.

	T-Values		
Number of reps	α = .05	α = .10	α = .30
2	12.71	6.31	1.96
3	4.30	2.92	1.39
4	3.18	2.35	1.25
5	2.78	2.13	1.19
6	2.57	2.02	1.16
7	2.45	1.94	1.13
8	2.37	1.90	1.12
9	2.31	1.86	1.11
10	2.26	1.83	1.10

EXAMPLE PROBLEM

The following is a walk-through example of the research process outlined in the previous section. All worksheets are at the back of this guidebook in the appendix. It may be especially helpful to follow steps 7.1 through 7.6 if you're not comfortable with the math.

1) Ask a question (see Worksheet A-1)

You normally apply all of your nitrogen preplant. As a rule, you put on more than the recommendations call for because you plan on some of the nitrogen (N) being lost to leaching or denitrification. You've been thinking that if you apply the nitrogen in a split application (half at the time of planting and half sidedress), you might be able to use only the recommended amount of N. You decide to conduct an experiment to test this idea.

After giving it some thought and talking to others, you come up with a researchable question: Will corn yields following one-time preplant N application equal corn yields following N split-applied (half at planting, half sidedress)?

2) Draw a diagram of the plot plan (see Worksheet A-2)

Your study only has two treatments, preplant and split-applied, and both treatments will be applied at the same rate. Your equipment is all eight-row, and you plant 30-inch rows. Each plot will be one round or sixteen rows. Using Formula 1, you calculate that you'll need 480 feet to accommodate the twelve plots needed to replicate the comparison six times.

Formula 1.
[row width (in inches) × row number (per plot) × number of plots] / 12 = total width (in feet)

[30 × 16 × 12] / 12 = 480 feet

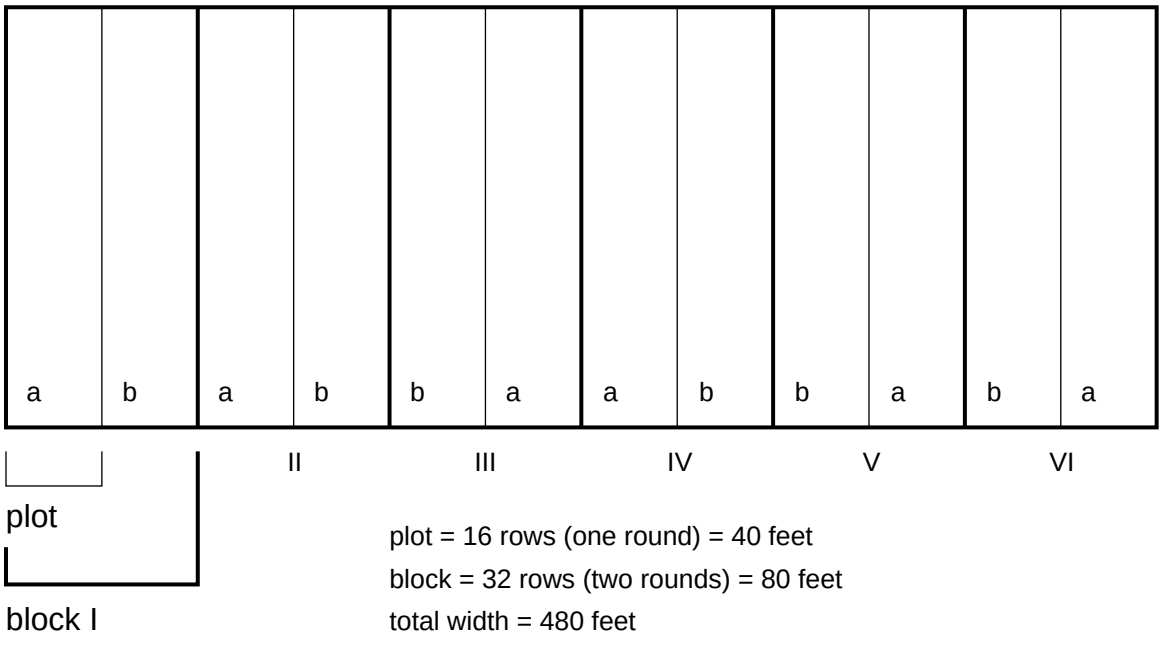
3) Choose the field and location

You choose a fairly level field large enough to accommodate the experiment and of soil type typical of the farm. The next step is to get out your completed plot plan (prepared from Worksheet A-2) and a coin. You assign heads to the preplant treatment (a) and tails to the split-applied treatment (b). The first flip is heads, so strip 1 will receive nitrogen preplant and strip 2 will receive its nitrogen by split-application, half at the time of planting and half sidedressed. You've assigned one block (or repetition); now you do the same for the remaining five. Your plot plan ends up like Figure 5.

4) Measure off the field

With plot plan in hand, you go out to the field. Ideally, there will be enough room to buffer the whole experiment with at least a round or two on all sides of the experiment and a round on the end. You have to lay out the plots and mark them before

Figure 5. Randomized complete block design with two treatments (a and b) and six repetitions (blocks I-VI)



you plant so that you know where to put the preplant nitrogen. Using a transit will help keep it all square.

You decide to label the plots with survey flags, using different color flags for each of the two treatments. The flags mark where each treatment goes and are meant to last throughout the season. You set the flags at the left corner of each plot.

For this experiment, the only measurement that is useful is the grain yields. Planning ahead, you confirm a source for a weigh wagon that you can use at harvest time.

5) Apply the treatments

Spring arrives, and it's time to apply the treatments. You put out your preplant nitrogen at the straight, recommended rate of 120 lbs per acre on all the plots marked "a". At planting time you apply the second treatment, nitrogen at a rate of 60 lbs per acre, to the plots marked "b" on your plot plan. At about the fifth leaf stage, you sidedress the b plots with another 60 lbs per acre. You make a note of all this in your notebook (the one that you carry everywhere in your shirt pocket). Everything else that has been done to the plots (tillage, weed control, other fertilization, etc.) is done in the same manner on all twelve plots.

Now your treatments are applied. In essence, what you have done is to hold everything constant except for one aspect. Now you can measure how yield reacts to the timing of nitrogen application.

6) Collect the data (see Worksheet A-3) and harvest plots (see Worksheet A-4)

The most important data for this experiment is the yield, but that doesn't mean you shouldn't inspect the plots during the course of the season. Look the plots over from time to time and note things that you may want to remember later. For example, weed or insect infestation may be especially heavy in one or more of the plots. Such information can help you explain your final results.

It has come time to harvest your research plots. Arrangements were made earlier for a weigh wagon and helper for the morning. Your plots are sixteen rows wide, but you do not want to harvest all sixteen rows because it is best to have buffer rows between each plot. Therefore, you harvest only the center eight rows from each plot. This practice leaves eight rows between each harvested treatment. You do not harvest the edge rows of each plot because the treatments can bleed into each other there and confuse the effects.

Table 3. Completed sum of squares calculations.

	Treatments		Difference (C)	Deviation (D)	Deviation squared (D^2)
Blocks (r)	A (preplant)	B (split)	C = (A - B)	$D = C - C_{avg}$	$D^2 = D \times D$
I	141	150	-9	-2.2	4.84
II	147	156	-9	-2.2	4.84
III	149	155	-6	0.8	0.64
IV	151	157	-6	0.8	0.64
V	149	150	-1	5.8	33.64
VI	142	-1	-10	-3.2	10.24
Totals	879	920	-41		$D^2_{tot} = 54.84$
Averages	$A_{avg} = 146.5$	$B_{avg} = 153.3$	$C_{avg} = -6.8$		

Table 4. Type I and type II errors and consequences.

		Actual Situation	
		differences exist	**differences do not exist**
Observed Situation	**differences exist**	correct decision	Type I error
	differences do not exist	Type II error	correct decision

If the field is long, it will not be convenient to harvest one pass and drive all the way back to the weigh wagon with the load for each plot. There is no right or wrong way to organize your harvest—just figure out what will work best for you. Most importantly, remember that each plot must be weighed out *separately*. If all the plots of one treatment are harvested together and the individual plot weights are not collected, there will be no way to calculate the variance and the numbers will be useless for statistical analysis.

7) Analyze data (see Analysis Worksheet)

Now it's time to analyze the harvest data. Analysis should be done on the bushel-per-acre figures calculated from Line J in Worksheet A-4 in the appendix. Table 3 shows what the completed calculations for the sum of squares should look like for this sample problem.

7-1) Analysis

Transfer the data from your data sheet to the Analysis Worksheet.

7-2) Calculate the variance.

variance = D^2_{tot} / (r-1)
D^2_{tot} = 54.84
(r-1) = (6-1) = 54.84
54.84 / 5 = 10.97

7-3) Calculate the variance of the means.

variance of the means = variance / r
10.97 / 6 = 1.83

7-4) Calculate the standard error.

standard error = square root of the variance of the means
$\sqrt{1.83} = 1.35$

7-5) Calculate the least significant difference (LSD).

Take the answer from step 7-4 and multiply it by the appropriate t-value. In order to find the appropriate t-value, you must first choose an alpha level. You're not sure what alpha level to use, so you think about the consequences of the type I and type II errors. Table 4 can help you here.

Let's assume that the results show that split application shows a higher yield, when in reality no difference exists. That is a type I error. If you decide to switch to the split-application based on these false results, the consequences would be the price difference of the two treatments (because split application would entail an additional trip across the fields).

If the results indicate that the timing of nitrogen application has no effect on the yield, when in reality there is a difference, then a type II error has been made. If you believe these false results and go back to preplant application for the sake of convenience, your yields may suffer.

After weighing the consequences, you decide to reduce your risk of making a type I error. So you choose an alpha level of α=0.05. Therefore, a t-value of 2.57 (the t-value comes from Table 2 on page 11) is used to calculate the LSD.

standard error × t-value = LSD
1.35 × 2.57 = 3.47

7-6) Look for a significant difference.
Take the answer from step 7-5, the LSD, and compare it to the box from Table 3 on page 13 labeled C_{avg}.

LSD= 3.47 C_{avg}= -6.8

C_{avg} is a negative value, so you ignore the negative sign. The C_{avg} (6.8) is greater than the LSD (3.47); therefore, the observed difference is significant (at an alpha level of 0.05). The yield increase observed under the split-application treatment can be considered real.

From this conclusion, you may infer that N applied preplant is subject to loss and that that is what occurred in this experiment. You may also infer that the loss may be reduced by split applying the N.

In addition, based on the experiment results, you may decide that although it is justified with preplant application, the use of N above the recommended rate as a form of insurance is not necessary with split application. Remember, though, that it is always a good idea to repeat an experiment more than once. It's not wise to base a decision on only one year's data.

Appendix

Worksheet A-1
Defining the experiment: question, treatment, comparison.

Question:

Treatments for this study would be

1.

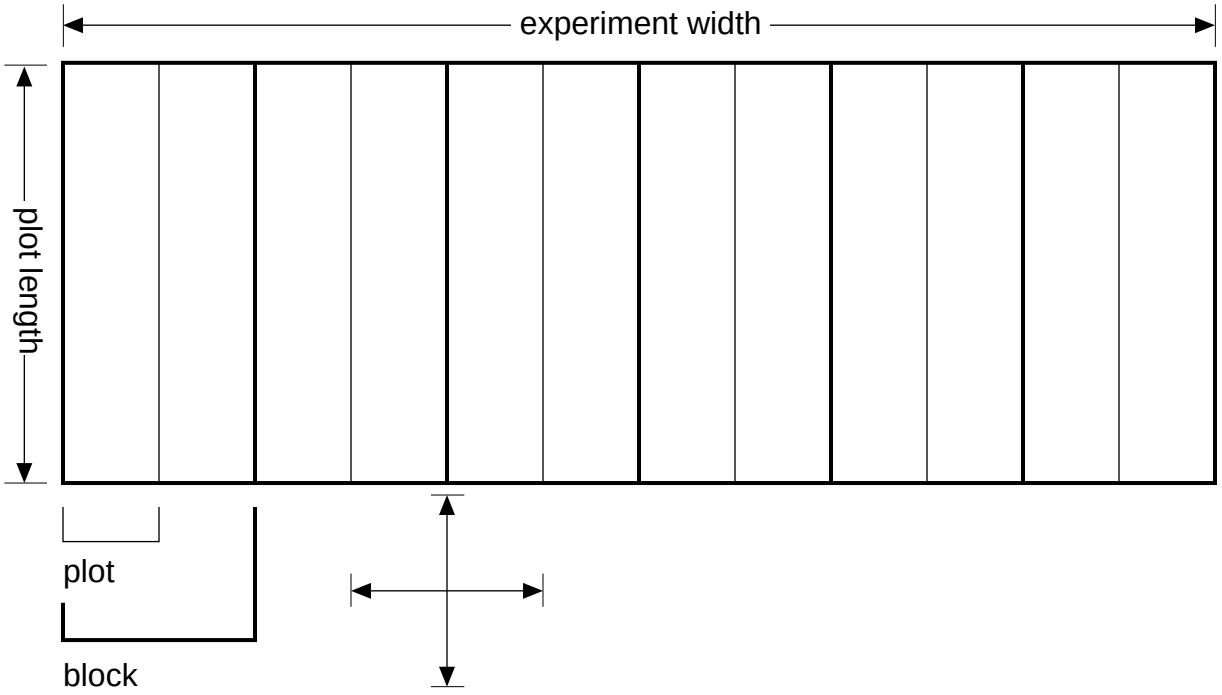
2.

3.

4.

The comparison then is treatment 1 versus treatment 2 versus treatment 3 versus treatment 4 and so on.

Worksheet A-2
Plot plan



Formula 1: [row width (in inches) × row number (per plot) × number of plots]/12 = total width (in feet)

The number of treatments equals the number of plots per block.
Randomize treatments within each block.

Worksheet A-3
Data collection

Use a separate sheet for each thing you measure.

Measurement _____

Plot	Sample 1	Sample 2	Sample 3
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			

Worksheet A-4
Yield calculation

PLOT #

Line A — Percent moisture at harvest _____

Line B — 100 - Line A _____

Line C — Pounds of grain harvested _____

Line D — Line B × Line C _____

Line E — Line D × 110.465 (shelled corn)
× 89.7655 (ear corn)
× 100.138 (soybeans) _____

Line F — Plot length (feet) _____

Line G — Row width (inches) _____

Line H — Number of rows harvested _____

Line I — Line F × Line G × Line H _____

Line J — Line E/Line I* _____
* Bushels of 15.5% moisture corn per acre or bushels of 13% moisture soybeans per acre.

The worksheet is based on the following formula. You can use the formula if you find it easier.
(100% percent moisture at harvest) × pounds of grain harvested × 110.465 (shelled corn)
or
× 89.7655 (ear corn)
or
× 100.138 (soybeans)
divided by (row length in feet × row width in inches × number of rows harvested)
equals bushels of 15.5% moisture corn or 13% moisture soybeans per acre.

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Analysis Worksheet

	Treatments		Difference (C)	Deviation (D)	Deviation squared (D^2)
Blocks	A	B	C = (A - B)	$D = C - C_{avg}$	$D^2 = D \times D$
I					
II					
III					
IV					
V					
VI					
Totals					D^2_{tot} =
Averages	A_{avg} =	B_{avg} =	C_{avg} =		

Step 7-1. Analysis
Transfer the data from your data collection sheet, worksheet A-3, to the above table.

Step 7-2. Calculate the variance.
variance = $D^2_{tot}/(r-1)$

Step 7-3. Calculate the variance of the means.
variance of the means = variance/r

Step 7-4. Calculate the standard error.
standard error = square root of the variance of the means

Step 7-5. Calculate the least significant difference (LSD). Take the answer from step 7-4 and multiply it by the appropriate t-value.
standard error × t-value = LSD

Step 7-6. Look for a significant difference. Take the answer from step 7-5, the LSD, and compare it to the box from table 1 labeled $C_{avg.}$
LSD= C_{avg} =
Conclusions:

If the C_{avg} is a negative value, you ignore the negative sign. If the C_{avg} value is less than the LSD, then the two treatments are not significantly different.

Notes

Notes

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