On-Farm Research Guide

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ORGANIC FARMING
RESEARCH FOUNDATION

> "Farmers constantly experiment. We try new products, new methods, new management styles, all within the domain of an ever-changing mother nature."
> --Mas Masumoto, *Epitaph for a Peach: Four seasons on my family farm*

You can answer many questions about your farm doing research using the scientific method. The scientific method has three basic steps: formulating a hypothesis, testing the hypothesis with experimentation, and drawing a conclusion based on the data.

Experimental basics

Experiments are done on portions of the farm, seldom on the entire farm. The mathematical techniques of statistics are used to calculate the odds that what you are measuring on one part of the farm will hold true for the whole farm. In order for this to work, measurements must be taken systematically. While not absolutely necessary, consulting with someone experienced in designing experiments for statistical evaluation—such as an extension agent, university researcher, or crop consultant—can help you avoid making mistakes that will render the data useless.

Reduce variation

Variety may be the spice of life but research demands rigid standardization. In doing an experiment, you want to control all external sources of variation as best you can. This helps to ensure that observed differences are more likely to have been caused by treatments you applied. It is impossible to have complete control of a project, especially one being done outdoors on a working farm, but it is possible to minimize variation in two ways: to establish research plots on relatively uniform ground, and to treat all plots exactly the same except for the treatments you are testing.

For example, to see how well a rye cover crop reduces weeds, cultivate the field that had rye exactly the same number of times you cultivate the field without rye and treat all plots exactly the same. Select fields for experiments that are similar and have comparable weed pressure or you will have trouble comparing the different treatments.

Establishing the experiment in the field

Field experiments are seldom carried to a conclusion if they aren't designed to be relatively easy to maintain. In the planning stages, decide what size your plots will be and where they will fit best. On-farm research typically uses plots that are field length and one or two tractor passes wide. This makes it easier to apply treatments along the entire strip without having to start or stop in the middle of the field.

When I was a research technician, I spent a lot of time in the field with a measuring tape marking the boundaries of plots. Flags or fenceposts are useful to mark where one treatment ends and the next one begins at planting, when applying treatments, and at harvest. Such markers can easily be knocked over or ripped out with machinery so be careful and immediately replace any that are moved.

To control external variation when you are comparing two treatments, make sure that each pair of plots runs across uniform areas of the field. If you are looking at more than two treatments, site each block in as uniform an area as possible. If there is a slope in the field, or a rocky area or any other feature that breaks up the uniformity of the field, locate plots so they all run across it and are affected equally by it. If it's a small outcropping or depression, avoid including it in a plot altogether if possible. Locate plots on either side of it and use the area over it as an alley or border.

Fields adjacent to your research fields may generate runoff or drift that can contaminate the research plots. Use plot borders or buffers to minimize this potential source of variation. In Nebraska, we planted 6-12 rows around each experiment to protect it from such influences.

The importance of taking notes

The devil is in the details, and when you break most field-level research down, it primarily consists of repetition and documentation. Documentation is singularly important for two reasons: it allows others to duplicate your experiment to verify it, and it gives you a record to look back on when you're trying to figure out what went wrong—or right.

Keep a notebook dedicated to the research project. Record any disease, insect, or weed problems that could affect growth of the crops. You may be able to see differences between the treatments in the way the crop responds to such problems. Make a note of it if you do. It's surprising how quickly differences that stand out in the spring may not be noticeable, or remembered, even a few days later, so make sure to write your observations down right away.

It is useful to draw out a plot map or plan to help visualize the project and to keep track of which treatment has been applied where. Make sure that any changes you make in the field are reflected on your map. Make at least one copy of the plot map and keep it somewhere safe so that you don't lose all your work if you lose your working copy of the map.

It is a good practice to document the weather, such as rainfall or any disasters such as hail, hurricanes, or freezes. A rain gauge is indispensable for documenting rainfall and can be more accurate than a local weather station.

Finally, compile a field history for the past 5 years that documents crops grown, tillage operations, inputs applied, and yields in the experimental fields. Past management can strongly influence present performance and provide valuable clues to why things turned out the way they did.

Making measurements

In research, part of the farm is controlled and measured in order to make projections about how the whole farm will respond. Similarly, in making measurements it would take a prohibitively long time to, for example, separately weigh all the millet heads in a plot, so you sample a certain number of them to represent the entire population of millet heads. Sample size should be determined using statistical methods if your experiment is for publication in a scientific journal. Otherwise, you can be guided by plot size and time constraints. You need to collect samples from each region in the plot in order to have representation from the entire area, but you don't want to spend days at the scale, either. You trade a degree of accuracy for pragmatic concerns, a trade-off that is made constantly in research.

Once you have an experiment established in the field, there is no limit to the kinds of data you can measure: date different growth stages are reached, plant height, leaf number, chlorophyll content (using a chlorophyll meter), weed counts, yield, quality parameters (protein or Brix levels, fruit size, insect damage, moisture, test weight, etc.), and anything else you want to know about. Be sure that what you are measuring will be useful in answering your research question. Most agronomic research focuses on measuring yield and quality parameters.

Harvest

Planning harvest in advance can help you concentrate on bringing in the sheaves rather than shuffling paper. Line up your equipment and paperwork well before the harvest date so that you don't waste valuable time when it's time to bring the crop in. Most of what you harvest will become part of your total production, but until you've completed measurements on it, keep it separate. Make a data sheet on which you can record the information you gather. It may help to assign different numbers to plots, treatments, or blocks.

At harvest, measure yields from each plot. This can be done with a weigh wagon, yield monitor, or by bagging and labeling individual plot yields and carrying them to a scale for weighing. Local extension agents, university researchers, or seed dealers may have access to specialized equipment for harvesting plots and will usually work with you if you ask them in advance.

Keep track of which yields come from which plot. Make a note of the harvest area from each plot so that plot yields can be converted to pounds per acre. Never lump all the yields from one treatment together into one measurement and plan to get an average value—this defeats the purpose of replicating (explained below).

To avoid edge effects, select the center rows to harvest from each plot. Cut a couple of feet in from each side of the plot. If you have to stop for the day before the entire experiment is harvested, make sure to complete a pair or block of plots to keep variation out.

Replication, randomization, and use of a control

Replication, **randomization**, and **use of a control** are essential in designing an experiment because they help to separate out treatment effects from natural levels of background variation. Without these three factors, any data you gather will be just about worthless. In research, **error** refers to anything besides your treatment effects that is measured. Setting up the experiment in a structured way helps to reduce the amount of error in your experiment; replication, randomization, and use of a control allow you to use statistics to actually separate out error from treatment effects in your measurements.

replication: You know that yields vary from year to year due to different rainfall, temperature, and other factors. Yield also often varies from location to location within a field because of high and low spots, inherent fertility, variation in soil types, etc. This natural variation is why replication is essential in experiments. The more times a treatment is duplicated, the more likely it is that measurements will reflect the effect of the treatment rather than the effect of natural variation in the field. However, there is a point of diminishing returns after which increasing replications doesn't give increased accuracy. University-based small plot research often has four replications or “reps.” Practical Farmers of Iowa use six replications in their long strip comparisons. There are statistical methods to calculate the exact number of replications necessary for any given experiment, but in most cases between four and six reps is adequate for on-farm experimentation.

There are different ways to replicate an experiment. One way is to have multiple plots at one location. Another way is to replicate the experiment on many farms. Another way is to replicate across time, performing the experiment in multiple years. Each type of replication adds to the confidence you can have in the results.

randomization: To prevent unanticipated sources of bias from entering your data measurements, treatments must be randomized. This means that the order of treatments cannot be the same in every replication. Say your field is on a slight slope, and the amount of soil moisture decreases as the field slopes up.

downhill/moist→ → → → → uphill/dry

Mulch	No mulch	Mulch	No mulch	Mulch	No mulch	Mulch	No mulch
Rep 1		Rep 2		Rep 3		Rep 4	

In every pair of treatments, the mulch treatment will perform better than the no-mulch simply because of its relative location on the moister ground. To avoid such problems, randomize the treatments within each replication:

downhill/moist→ → → → → uphill/dry

No mulch	Mulch	Mulch	No mulch	Mulch	No mulch	No mulch	Mulch
Rep 1		Rep 2		Rep 3		Rep 4	

You can flip a coin to determine the placement of each treatment in a rep if there are only two, draw slips of paper from a hat, or use a random numbers table found in most statistics texts.

using a control: The treatment is *the procedure or product whose effect is to be measured*. Having **control** plots where the treatment is not applied gives you a basis for comparison. If you are researching a new practice or variety, the control would be a plot that receives your normal practice or variety. For example, in variety trials the control is usually the traditional, established variety whose performance is known. If you are researching the effects of a particular input, the control would be a plot that isn’t treated with that input. In fertility studies, the control receives no fertilizer. In designing an experiment, it is essential to include a control so that the effects of your treatment can be measured against something not receiving that treatment.

Now that we’ve gone over the basics, let’s dive into planning the experiment.

Forming a hypothesis

The first challenge in planning a research project is to focus your larger production question into a well-defined question or statement that can be answered with data. This is the hypothesis. A hypothesis is a testable statement that forms the basis of the experiment.

Often in on-farm experiments, the overall topic needs to be honed down to a more specific hypothesis. Here are some research topics written by farmers:

1. Wood chips as a mulch in organic vegetable production
2. Legume cover cropping in date gardens
3. Using turkeys to weed asparagus
4. The effects of soil tillage on soil quality, the effects of different soil amendments and cultural practices on soil fertility

Each of these topics contains a researchable question, but the challenge is to narrow the focus onto specific treatments whose effects can be measured. Keep in mind that the fundamental purpose of research is to *measure a controlled part of the system in order to make generalizations or predictions about the whole*.

For topic 1, we may want to focus the study on two or three of the farmer's vegetable crops to make it a manageable project. Keeping track of the mulch's effect on 20 crops may involve too many logistics and introduce that many more sources of error. What effect of the mulch are you interested in? Wood chip mulch can help suppress weeds and can increase the amount of carbon in the soil, perhaps affecting the microbial activity of the soil. Taking these considerations together, we make the hypothesis:

> Wood chip mulch applied in a thin surface layer reduces weeds and increases soil microbial activity in organic pumpkin, corn, and turtle bean production.

Using a similar process, each of the other broad research questions shown can be whittled down to a testable hypothesis.

Testing the hypothesis

Making a hypothesis is the first step in research. Designing an experiment to test the hypothesis is the next step. Testing the hypothesis involves figuring out what treatment or treatments you will apply, deciding what you will measure, and planning how you will set it up in the field. Testing the hypothesis also involves gathering and analyzing the data.

Experimental designs

Experimental design is a way to arrange treatments so that error and bias are reduced and the data may be accurately analyzed using statistics. Design and analysis fit together to make a meaningful whole. If an experiment has a poor design, you can't have confidence in what the data are telling you.

Standard experimental formats or designs are usually used in on-farm research. The criteria used to select which design fits which experiment depends on the number of treatments under investigation. If you want to compare two levels of a treatment, you can use a design called a *paired comparison*. An easy statistical analysis, the t-test, can be performed on the data to detect any significant differences. If you want to add more levels of treatments, you can use a *randomized complete block* design. A *split plot* design allows you to see how different treatments interact. These designs can provide you with more information than the paired comparison but also require more sophisticated statistical analyses and more space in the field. Because each treatment must be replicated at least 4 times, each treatment increases the research area required.

1. The paired comparison

This classical on-farm design is characterized by having long strips side-by-side in the field, replicated up to six times. Each pair of strips should be located in an area that is fairly homogeneous or similar. Typically, strips are field length and one or two tractor passes wide. This makes it easy to apply treatments along the entire strip without having to start or stop in the middle of the field. A general principle is to avoid “edge effects” by taking measurements from the center of the plot.

The paired comparison is an excellent way to assess the effects of separate components on a crop. Growing corn with and without starter fertilizer or mulch, comparing two varieties, cover cropping compared with fallowing--in a homogeneous field, any pair of treatments can be effectively compared using this design. If there is a large amount of variation in the terrain, some kind of blocked design is required to remove or “block out” the effect of this variation on the measurements.

Mulch	No mulch	No mulch	Mulch	Mulch	No mulch	No mulch	Mulch	Mulch	No mulch	No mulch	Mulch

Paired block comparison measuring the effect of mulch compared with no mulch using 6 replications. “No mulch” plots are the controls.

An excellent guide to analyzing the data from a paired block experiment with the t-test is presented in the Rodale Institute’s “A Farmer’s Guide to On-Farm Research” (see resources below).

2. The randomized complete block

The randomized complete block (RCB) design is used for experiments looking at three or more levels of a treatment in areas with topographic variation on a gradient, such as on a slope. It is similar to the paired comparison in that all treatments are grouped together in blocks that are replicated across the field. The purpose of “blocking” the treatments is to maintain as much uniformity as possible in each block and keep environmental variation outside of the blocks. Blocking doesn’t help when variation in the field is random, but can reduce error when variation runs along a gradient such as a slope, irrigated field, changing soil texture, or other factor. Block borders ought to run perpendicular to the gradient (see figure). The treatments are randomized within each block to avoid bias. In this design, blocks are synonymous with replications because a complete set of treatments is replicated in each block.

The statistical test *analysis of variance* is used to analyze the data from an RCB. Analysis of variance can be calculated by hand but because of the large number of arithmetical steps it is usually done using a computer program. Statistics software is widely available, and your extension agent or cooperating researcher can assist in analyzing the data from an RCB or split plot experiment.

downhill/moist → → → → → uphill/dry

Pea	Vetch	None	Vetch	None	Pea	Vetch	Pea	None	None	Vetch	Pea
Rep 1			Rep 2			Rep 3			Rep 4		

Randomized complete block design on a topographical gradient (slope) with 3 treatments (pea, vetch, and none, the control) arranged in 4 replications.

3. The split plot

The split-plot design looks at how different levels of a treatment interact with another set of treatments by applying subtreatments over main treatments. Statistically speaking, you sacrifice precise information on the main treatment for more precise measurements of the subtreatments simply because the subtreatments are replicated more than the main treatments. Though fairly easy to set up in the field, analyzing the data can be somewhat complex. Because of the greater number of treatments, adequately replicating a split-plot experiment can take much more space in the field. Work with someone knowledgeable in statistics to set up a split plot experiment.

-------------- Rep 1 ----------------------- -------------------- Rep 2 --------------------

compost	Fish	None	Fish	None	compost	compost	None	Fish	None	compost	Fish

fallow pea pea fallow

Split plot experiment with 2 main treatments (pea and fallow) and 3 split treatments (compost, fish, and none) replicated 2 times. The fallow-none plots are the controls.

<u>Drawing a conclusion based on the data</u>

It can be difficult to tell just by looking at the data whether any differences are due to random variation or to treatment effects. Statistical analysis re-orders the data that were randomized in the field and performs mathematical computations to determine the probabilities that the differences were caused by normal variation or by the treatments. The results of the data analysis give you the basis for making conclusions on the effects of the treatments.

Analyses can be performed using different confidence levels. Professional researchers typically choose a 95% confidence level, which means that there is a 95%

chance that the measured differences are due to the treatments rather than to random variation or error. There is a 5% chance that the analysis will lead you to conclude there were differences where there were none or vice versa. In scientific literature, this chance of wrongly interpreting the data is indicated as $p < 0.05$ (probability is less than 5% that the analysis is picking up on non-existent differences or not measuring real differences).

In reality, you will never be 100% sure that you have proved or disproved your hypothesis. Statistics are based on tendencies and likelihoods, never on certainties. If you ever come across a scientific study that claims to have 100% accuracy, be suspicious. 99%, 99.5%, 99.9% are achievable probability levels, but never 100%. There is always a 1%, 0.5%, 0.1%, or even 0.0001% chance of error and honest researchers will acknowledge this.

An example

Hypothesis:

Wood chip mulch applied in a thin surface layer reduces weeds and increases soil microbial activity in organic bell pepper production.

Testing hypothesis:

We'll set up this experiment on a vegetable farm using raised beds. The wood chip mulch will be the treatment and no mulch will be the control. We'll use 6 replications, which means 12 beds are needed. A block consists of two beds, one receiving wood chip mulch and one not. The treatments are randomized in each block.

Before planting and applying the mulch, take soil samples from each of the beds and have them analyzed for microbial biomass as indicated by CO_2 release. Establishing a baseline of microbial biomass will give you more to go on in making the treatment comparisons. Soil sampling procedures are critically important in obtaining useful information. To make sure that tests on soil samples are accurate, careful handling is necessary. This is particularly true for samples that are used to indicate biological activity. Keep samples in an ice chest, and consult with your soil testing lab for proper sampling procedures. To get an accurate measurement of microbial biomass, make two composite soil samples for each bed consisting of ten soil cores. Sample each composite (10 cores mixed in a bucket) twice. Keep samples separate and carefully label them so you know where they came from. Subsampling in each plot creates mini-replication within the plot just in case there is variation in microbial activity within the plot.

Beds are all prepared and planted exactly the same except for the use of mulch on the treated plots. Plant two rows of bell peppers in each 30'-long bed.

Mulch	No mulch	No mulch	Mulch	Mulch	No mulch	No mulch	Mulch	Mulch	No mulch	No mulch	Mulch

rep 1 rep 2 rep 3 rep 4 rep 5 rep 6

Record date of planting, sowing rate, and moisture status in the notebook and make notes throughout the growing season of anything that may affect bell pepper growth. Sketch a map of the experiment as shown above.

To measure the mulch's effect on weeds, take weed counts on each plot three times throughout the growing season: at 3 weeks, at 5 weeks, and just before harvest. Subsampling in each plot is useful so that you don't have to count all the weeds in every bed. There are many ways to measure weed subsamples. The easiest is to make a foot-square template out of narrow PVC pipe to throw randomly on each bed a few times. Then count the weeds within the foot-square area and write it down. It is crucial to identify which plot each count came from. Making a data sheet can help keep track. Here's what the data for weed counts at 3 weeks might look like. Four subsamples were counted in each plot.

Date	Rep	treatment	count 1	count 2	count 3	count 4
	1	M	2	5	12	8
	1	NM	5	7	12	9
	2	NM	10	15	9	4
	2	M	3	6	9	12
	etc.					

M = mulch NM = no mulch area = 1 ft^2

If you use abbreviations, make a note of what they stand for! Also note the sample area size. What seems obvious one day may be only a vague memory later on.

You may as well look at the mulch's effect on yield, so hand harvest a 10' section of each bed separately. To avoid edge effects, harvest as close to the center of the plot as possible. Bag or box each of the plot yields in a labeled bag. You will have 12 bags or boxes of bell peppers. Besides yield, you can also take quality measurements on the fruit such as fruit size, color, insect damage, etc. Weigh the yields from each plot and record the yields on another data sheet. At some point you will need to convert the yields from pounds per harvest area to pounds or tons per acre. This involves some math. It's important that all comparisons be made between measurements in the same units, such as pounds/acre.

Finally, take another series of soil samples to test for microbial biomass to compare with those taken before the mulch was applied.

Drawing conclusions

Either analyze your data sets yourself or send *copies* of your data sheets to someone who will do the analysis for you. The t-test will end up giving an L.S.D. or least significant difference value for the two treatments. If the difference between the average values for each treatment is greater than the L.S.D., the treatment had a significant effect on the measured variable (yield, microbial biomass, or weed population). If the difference is smaller than the L.S.D., the treatment did not have a significant effect.

Bell pepper yields (lbs/plot)

Rep →	1	2	3	4	5	6	Avg.	L.S.D.*
mulch	260	304	310	253	360	275	293.7	6.3
no mulch	233	282	314	347	238	306	286.7	

*not actually calculated from the data set—for example purposes only

Because the difference between the treatment averages, 7.0, is greater than the least significant difference, we can conclude that mulch had a significant effect on bell pepper yield.

Soil microbial biomass at harvest (mg C/kg dry weight soil)

Rep →	1	2	3	4	5	6	Avg.	L.S.D.*
mulch	165	254	316	279	154	367	255.8	4.9
no mulch	245	178	257	282	331	269	260.3	

*not actually calculated from the data set—for example purposes only

Because the difference between the treatment averages, 4.5, is less than the least significant difference, we can conclude that mulch did not have a significant effect on soil microbial biomass. Close only counts in horseshoes, not in statistics, so it doesn't mean anything to have an L.S.D. that is very close to the difference between treatments. This conclusion is valid only if we assume there were no significant differences in microbial biomass between plots at planting.

Conclusion

On-farm research is a powerful decision-making tool for organic farmers. A lot of work goes into doing high-quality research, but the confidence you have in the results are worth it. Economic data can be included in the results and useful cost:benefit analyses of different farming practices may be generated. Groups of farmers can join together in research clubs and assist each other in investigating new varieties, practices, and inputs. Don't wait for your local land-grant university to finally study what you're interested in—go out and do it yourself.

Resources

Farmers have numerous resources available to them in planning, carrying out, and analyzing experiments. Here is a partial list:

Publications

A Farmer's Guide to On-Farm Research, by Rhonda Janke, Dick Thompson, Craig Cramer, and Ken McNamara. Rodale Institute Research Center. $5. 1-800-832-6285.

How to Conduct Research on Your Farm or Ranch, by Dan Anderson, Mark Honeyman, John Luna, and Valerie Berton. Sustainable Agriculture Network. Contains extremely valuable section on doing livestock research. Also lists many other resources. Free. 1-301-405-3186, www.sare.org/san/htdocs/pubs/

The Paired-Comparison: A Good Design for Farmer-Managed Trials, by Rick Exner and Richard Thompson. Free. 515-294-5486, dnexner@iastate.edu

On-farm Testing: A Grower's Guide, by Baird Miller, Ed Adams, Paul Peterson, and Russ Karow. Washington State University Cooperative Extension. Contains samples of data sheets. $1. 509-335-2857, drycrops.wsu.edu/crop_management/OFT/oftman.html

On-farm Trials for Farmers Using the Randomized Complete Block Design, by Phil Rzewnicki. Nebraska Cooperative Extension. Gives details on analysis. $2. 402-472-2821.

Organizations

Organic Farming Research Foundation, research@ofrf.org 831-426-6606

Practical Farmers of Iowa, 2035 190th St., Boone, IA 50036, phone 515-432-1560, website http://www.pfi.iastate.edu/

The Leopold Center for Sustainable Agriculture, Iowa State University, 209 Curtiss Hall, Ames, Iowa 50011-1050. 515-294-3711 leocenter@iastate.edu, http://www.ag.iastate.edu/centers/leopold/Leopold.html

The Rodale Institute, 611 Siegfriedale Rd., Kutztown, PA 19530-9320, 610-683-1400 info@rodaleinst.org, www.rodaleinstitute.org

Michael Fields Agricultural Institute, W2493 County Rd. ES, East Troy WI 53120, 262-642-3303, mfai@mfai.org; www.michaelfield.org