Ag Innovations Series

TECHNICAL BULLETIN

Peer-reviewed research findings and practical strategies for advancing sustainable agriculture systems

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How to Conduct Research on Your Farm or Ranch

2ND EDITION

Introduction

When Rich Bennett returned to the family farm in the 1970s to help his father, he faced some significant challenges. Poor soils and increasing fertilizer costs were straining the farm's bottom line. As a result, he began looking into new ways of farming that could improve his land and also improve the profitability of the business. Eventually, he succeeded: After experimenting with lower commercial fertilizer rates and incorporating cover crops into his grain rotation, Bennett decided to frost-seed red clover into his wheat every winter to supply crop nutrients and enhance soil quality. In the process, he reduced his fertilizer costs by more than half.

When starting out, Bennett had his own ideas, and he gathered information from other sources, but in the end, what dictated the changes he eventually decided to make?

On-farm research.

"Through on-farm research," Bennett said, "farmers gain insights into their own production system and how to produce for maximum profit, not yields." The value in on-farm research is that it provides reliable information you know will make a difference.

"Until you do research, you're really only guessing," said Vicki Stamback, an Oklahoma cut-flower producer who received a grant from USDA's Sustainable Agriculture Research and Edu-

David and Deborah Hansen used a SARE Farmer/Rancher grant to monitor the change in soil carbon caused when Eastern Redcedar chips were applied to native grassland pasture on their Nebraska ranch. *Photo by Marie Flanagan, North Central SARE*

cation (SARE) program to test greenhouse efficiency. "When you have the numbers in front of you, you know." After two years of experimenting with different greenhouse temperatures, Stamback determined the minimum temperature required to raise flowers in the winter most cost effectively. While most flower producers run their greenhouses at about 65 degrees, setting the thermostat as low as 45 degrees for flowers like ranunculus, sweet peas, lupine and fresia dramatically reduced Stamback's greenhouse heating bill. Moreover, she discovered that she could grow flowers like delphinium, larkspur and snapdragons without any supplemental heat. After performing the research, Stamback said she now "knows the best temperature to use, plus what crops to grow to make the most profit."

Simply stated, on-farm research is the application of proven research methods to an actual farm or ranch.

In on-farm research, farmers and ranchers conduct or help conduct the experiment, providing a real-life setting in which to test their theories. This publication will help you learn more about on-farm research. It will introduce you to the purpose and goals of on-farm research and show you how on-farm research works on real farms. If you are exploring on-farm research for the first time and just want to get an idea of what is involved, this publication will introduce you to the basic steps. If you are ready to plan and implement your project, this publication provides more specific information on experimental design, and how to lay out your field plots and analyze your data using basic statistical techniques. The focus is on-farm research for cropping systems, but some techniques for livestock and pasture-based systems are highlighted. We hope this publication will inspire you to go further in experimenting with new ideas on your farm.

What is On-Farm Research?

Like all natural systems, your farm or ranch is affected by environmental factors such as climate, weather, soils and topography, and by the interactions between the various plants, animals and microorganisms that live in that system. Farming in this complex and constantly changing environment raises a host of questions and problems as each day and each season bring new challenges. As a result, farmers and ranchers are always exploring new ideas and ways of doing things. In response to a problem or some new bit of information, you experiment with new techniques, tweak your production system, observe the results and draw a conclusion: It worked well, it did not work or you did not see any difference.

Systems Research Versus On-Farm Research

Although farms and ranches are complex "systems," when you conduct on-farm research you will most likely be following a "reductionist" approach because you will be isolating a certain part of a whole farming system in order to explain how that part works or responds to certain changes.

Due to the sheer size and complexity of whole-systems research, it would be impossible for you to conduct this type of research on your farm. Systems research projects are usually large scale, take place over many years or even decades, and often involve researchers from multiple disciplines.

However, throughout your research—from developing your question to analyzing and interpreting the results—try to maintain a broad perspective on the systems aspect of your farm. Note how changing one aspect of your system affects other parts. For example, if you were to study the effects of a cover crop on soil organic matter or soil nitrogen levels and found that the cover crop conferred some benefits to the soil, consider how adding this cover crop might impact your entire rotation, and, what other changes you might have to make to compensate for adding a new crop into the rotation.

To learn more about systems research, see the SARE book, *Systems Research for Agriculture*, as well as other information listed in the Resources section.

Funded Research in the SARE Project Reports Database

The SARE project reports database can help as you plan your research project. You can see what kinds of projects have been funded, what amount of reporting will be expected, and if other farmers or ranchers have done similar research and what they learned. Visit www.sare.org/project-reports to begin. When conducting a search, select "Farmer/Rancher Grant" under "Project Type" to limit results to projects conducted by other farmers and ranchers.

As you look into new practices, you need a way of knowing if the effects that you observe in crop yield or quality, in increased soil organic matter, or in water infiltration are a result of the natural variation that occurs within the farm system, or whether they are truly a result of changing practices. Just as university researchers try to control natural variability in small-plot or greenhouse experiments, you will use on-farm research to help you sort out specific questions and arrive at definitive conclusions. On-farm research takes your role as a researcher to a whole new level.

On-farm research is generally:

- Conducted on a working farm or ranch. If multiple farms are included in the study, a high level of coordination is required to minimize variability between the sites and ensure consistency in how treatments and practices are applied across farms.
- Conducted on a small part of the farm but uses plots large enough to allow for the use of standard field equipment and practical data collection.
- A partnership between between you, or you and a group of farmers, and agricultural agricultural service providers, including Extension, consultants, seed dealers, etc. Professional researchers may provide leadership, guidance and assistance, but you are directly involved in the design and management of the project.
- A process that uses clearly defined methods of experimental design with replications and statistical analysis (described later in this bulletin). These techniques allow you to identify and isolate the effects of natural variation so that the true effects of changing practices are more clearly detectable. Statistical analysis helps you conclude whether the differences you observe are due to the different treatments (practices) or are merely a result of chance, within certain levels of probability.

This last point—the use of statistics—distinguishes on-farm research from on-farm demonstrations or variety plots. On-farm *research* identifies and validates answers to a specific research question. In contrast, on-farm *demonstrations* are designed to show other farmers a new technology or production practice. Since on-farm demonstrations do not have research components, you do not need to measure or analyze yield responses or other data—instead, you observe and note any results or trends in the field, and then share those outcomes with other farmers. Variety trials can fall under either category depending on their purpose and how they are planned: If you use established research methods to compare the performance of two or three varieties under the same growing conditions, then those trials would be classified as on-farm research; if you plant large plots of several varieties (one variety each in several large plots), that would be an on-farm demonstration.

A Realistic View

On-farm research can help you solve problems on your farm, assess new practices and determine the effects of changing your production system in some way. The methods used in on-farm research will give you confidence in the results and answers you get. But on-farm research also has a number of drawbacks. Some of the major challenges include:

- **Time and effort.** It takes a lot work to design and implement an on-farm research project. For best results, most research projects should take place over at least two growing seasons. In order to make your project a success, you will need to take this additional time and effort into account as you develop your work plans for the coming season.
- **Coordination.** Similarly, on-farm research must be coordinated with your regular farming activities. Key areas for coordination include field and plot layout and separation, planting, managing research plots correctly, and harvest and data collection.

Apply for a SARE Grant to Conduct On-Farm Research

Over the years, dairy farmer Tom Trantham has participated in three kinds of SARE grants involving on-farm research and demonstration, an experience that helped him successfully transition to a pasture-based system (see his profile). Through its nationwide competitive grants program, SARE sponsors research and education projects that advance—to the whole of American agriculture—innovations that improve profitability, stewardship and quality of life. Between 1992 and 2016, SARE funded about 2,600 small grants for farmers and ranchers to conduct on-farm research.

To learn more, visit www.sare.org/Grants/Apply-for-a-Grant and follow the link for your region of the country. Each region has its own guidelines for how to apply, what kinds of activities can be proposed, funding amounts and collaborators—so read the Calls for Proposals and supplemental information carefully. Proposal workshops and other project development resources are also available, including a recording of the webinar, *Successful Research Design and Methodology for Grant Proposals* (see Resources).

- **Costs**. On-farm research may involve extra expenses for planting and managing field plots, collecting data, and any specialized tests that you run on soil or plant samples.
- **Knowledge and skills.** On-farm research also requires some expertise in planning and design, managing the field experiment, and collecting and analyzing data. You will need to either develop these skills yourself or seek others who can help in these areas. Technical advisors are particularly important for experimental design and statistical analysis.
- **Managing expectations.** With on-farm research, you must strive to be objective and to accept the results that emerge from the project, even if they are not what you expected. The hope is that you will find the answers you are looking for, and with the proper research methods, that will most often be the case. Even a "failed" experiment usually provides useful information.

Given the challenges outlined above, where can you go for help? Your state land grant university and Cooperative Extension service is a good place to start. Try contacting your local county agent, county faculty or farm advisor and let them know what you are thinking about. First, they can probably tell if your question or problem has already been addressed: The information you need may already be available. Second, if you decide to go forward with your project, they may have resources and information that will help you narrow the focus of your project and design a project that matches your needs and capabilities. You may also want to contact your state SARE coordinator, who can connect you with other farmers or researchers who might be able to assist you (www.sare.org/state-programs). You can also search the SARE project reports database to read about other types of on-farm research projects that might have relevance to your own. Lastly, check out the many resources listed at the end of this publication, which provide additional information about on-farm research.

For more information on applying for SARE funding to conduct on-farm research, see the Apply for a SARE Grant to Conduct On-Farm Research box.

Wheat farmers and Montana State University researchers partnered to conduct on-farm research looking at practices to reduce ammonia gas emissions from surface-applied nitrogen fertilizer. Among their findings was that the soil disturbance created by air-drill seeders was not sufficient to mitigate ammonia loss (right) compared to no-till (left). *Courtesy Montana State University*

PROFILE **Tom Trantham, 12 Aprils Dairy**

On-Farm Research Answers Key Questions While Making the Switch to a Pasture-Based Dairy System

Although Tom Trantham was one of South Carolina's top dairy producers back in the 1980s, his business, 12 Aprils Dairy, was struggling. He ran a typical confined feeding operation and his feed bill alone ate up 65 percent of his gross income. "Financial advisors told me to get out of the business," Trantham recalled. "They said there was no way for me to make it. Those were dark days; I'd wake up and think maybe the place had burned down or all the cows had died in the night and I'd be free."

Then in April 1989, by chance, his cows broke out of the feeding area into a seven-acre field full of natural lush spring growth—lamb's quarters, ryegrass, a little clover and fescue. Trantham noted a two-pound average increase per cow in milk production the next day, and since then, things have never been the same. Thinking maybe the cows were trying to tell him something, Trantham opened all the gates on his farm and began the transition away from a confined feeding operation toward an entirely new pasture-based system. For Trantham, this transition raised some important questions:

- What types of plants (crop and forage species) can be grown to provide adequate and nutritious year-round grazing for the cows?
- Can alfalfa, or annual grains such as sorghum and millet, be included in the grazing sequence?
- Can this variety of crops be grown using sustainable agriculture methods (e.g., manure as nutrient source, no-till, minimizing the use of chemicals)?
- Is the new pasture-based system economical when compared to a confined-feeding operation?

Trantham approached Clemson University professors Jean Bertrand and Fred Pardue to help him find some answers. Together, they obtained a Southern SARE Research and Education grant to determine the feasibility of a minimum-input, financially sound grazing dairy. From 1994 through 1997, the SARE-funded researchers monitored Trantham's practices and recommended changes based on their findings. At the end of the project they had a body of scientific knowledge to help other farmers, and Trantham had a successful grazing dairy system.

"When I first started experimenting with grazing, production dropped to 15,000-pound average, but I still paid my bills because of the decreased feed costs," Trantham said. "Profits continued to improve as I moved further away from conventional dairying." Today, his milkers consistently top an 18,000-pound average, and he thinks they can do even better as he tweaks the system with irrigation, smaller paddocks and other improvements.

As a cooperator on a Southern SARE Professional Development Program project headed by Steve Washburn of North Carolina State University, Trantham toured grazing dairies in Ireland, seeking more ways to improve his system. "That's where I learned I needed to reduce my paddock sizes," he recalled. "I saw firsthand how moving them every day, or even every milking, can minimize paddock damage and allow faster regrowth. I learned a lot about irrigation options and came home to install more than $10,000 worth of irrigation on my farm, a risk I would have considered reckless in the days when I would have invested that much and more in feed supplements. But unlike feed supplements, the irrigation will pay off for the rest of my life, not just for this season."

Photo by Dennis Hancock, University of Georgia

Trantham also experimented with some lane materials as part of a Southern SARE Producer grant project. He continues to try new ideas and evaluate every part of the system for efficiency and cost effectiveness.

Through the SARE grants and a process of continuous improvement, 12 Aprils is now a thriving and profitable dairy. As the name of his dairy implies, Trantham's goal is to provide an April-type feed for his cows every month of the year. He achieves that by planting his 29 paddocks with a succession of crops that provide the type of growth the cows are most hungry for and that boost milk production. Trantham is quick to note that his emphasis on year-round crops makes his system an atypical pasture-based, rotational grazing system. It is not for everyone, and the crop mix is quite specific to his farm and geographic location.

"A lot of times, the questions we ask...the answer is not what we were looking for," Trantham said. "So, rather than asking what rye variety is best to plant in South Carolina, I found out that there are...other ryes, and you can find out that some of those come up quicker or last longer or take more cold. You need to know what performs better for your farm...and you can learn that from your own on-farm research."

LEARN MORE

Visit www.sare.org/trantham to find a video of Tom Trantham telling his story, reports from his SARE-funded projects and detailed information about his grazing system.

How to Develop an On-Farm Research Project

Where to begin? At the center of every on-farm research project is a question that needs to be answered. Think about some of the problems you are dealing with on your own farm or ranch, or any new practices that you have been exploring. Take a moment to write down some of those key problems and ideas and, if you have the opportunity, share them with other farmers in your network or association to get their input. Communicating with other farmers can help you define the problem and hone in on what is most important.

For example, Dennis Wright, owner of Fruitwood Apiaries in New Jersey, noticed many of the hives he leased out were not surviving during the pre-pollination period in large blueberry fields. He chatted with other pollinator service providers and discovered they were seeing the same thing. This made the question worthwhile to pursue, and in 2015, Wright received a SARE grant to try to figure out why. Read about that grant at mysare.sare.org/sare_project/fne15-833/.

As you work through this process, consider the kinds of questions that might emerge for each of the items on your list. Here are a few possible scenarios to spark your thinking:

- Your region of the country is experiencing a drought. Are there any changes you can make to your system to maintain productivity and profitability in the face of continuing low rainfall?
- You are seeing fuel costs skyrocket. Can you reduce tillage and still maintain the levels of production you need?
- You are observing problems with the soils on your farm (e.g., crusting, erosion, poor infiltration) and yields are down. Can cover crops provide nutrients for your cash crop and improve the quality of the soil?
- You are in the transition process to become certified organic. What methods can you use to prevent or control weed, insect or disease pests?
- You have heard about a new crop that you have never grown before. How will that new crop perform on your farm? Is there a market for it? How does it fit into your rotation?

Whether you are wondering about a specific practice, a change to your production system, farm profitability or environmental stewardship, on-farm research can help you address the questions you have about your own farm or ranch, and make wise management decisions accordingly. Whatever is on your list of opportunities and challenges can be the inspiration for an on-farm research project. But how do you move from general questions about your production system to a fully developed on-farm research project? The next section describes the process for reaching that goal.

The Process

Following these 10 steps will help you develop a successful on-farm research project.

1. **Identify your research question and objective.**
2. **Develop a research hypothesis.**
3. **Decide what you will measure and what data you will collect.**
4. **Develop an experimental design.**
5. **Choose the location and map out your field plots.**
6. **Implement the project.**
7. **Make observations and keep records throughout the season.**
8. **Collect research data.**
9. **Analyze the data.**
10. **Interpret the data and draw conclusions.**

Each of these steps is expanded on below, providing an overview of the entire on-farm research process from initial planning to implementation to drawing final conclusions. Keep in mind that the focus here is on crop-based research, but the same process applies in livestock- or pasture-based systems.

STEP 1: Identify your research question and objective. Identifying your research question involves moving from the general to the specific—from ideas or hunches to

A field is prepared for planting with replicated plots of malting barley. Four Wisconsin farmers used a SARE Farmer/Rancher grant to collect data on the performance of barley varieties under different fertilizer and tillage conditions. *Photo courtesy Joe Bragger, Bragger Family Farm*

TABLE 1: From Research Question to Research Hypothesis

RESEARCH QUESTION	HYPOTHESIS
Can a legume cover crop substitute for my standard commercial nitrogen fertilizer application?	A cover crop of hairy vetch before my cash crop will provide enough nutrients throughout the season to achieve my target yield.
Will a new tomato variety produce a higher yield than the standard tomato variety that I usually plant?	When planted and managed in exactly the same way, the new tomato variety will yield the same (or higher) than my current variety.
Can I eliminate a particular pesticide application, replace it with a more environmentally sound approach, and increase my bottom line per acre?	The alternative pest management strategy will increase my profit per acre by 10 percent over my current strategy.
Will changing my tillage practices change the amount of irrigation I need? Or, if I switch to a no-till or reduced-tillage system, will my yields be reduced?	The reduced-tillage system being tested will result in the same or higher yields than my current system. Or, it will reduce the amount of irrigation my crops require.

a clear objective—and selecting just one yes-or-no question to answer. In developing your question, consider your own capabilities and if the information needed to answer the question is actually measurable. The question will usually ask whether a new approach is an improvement over the current one or if it will help you meet some goal or objective. Here are some sample research questions:

- Can a legume cover crop substitute for my standard commercial nitrogen fertilizer application?
- Will a new tomato variety produce a higher yield than the standard tomato variety that I usually plant?
- Can I eliminate a particular pesticide application, replace it with a more environmentally sound approach, and increase my bottom line per acre?
- Will changing my tillage practices change the amount of irrigation I need? Or, if I switch to a no-till or reduced-tillage system, will my yields be reduced?

You can think of the research question as a comparison between two or more practices. The examples above compare: a cover crop versus commercial fertilizer; the performance of one variety versus another; a pesticide versus an alternative pest control practice; and a current tillage practice versus a reduced-tillage practice. The practices compared in the research project are called treatments. To further clarify your intent, you may also want to re-write the research question as an objective. Using the legume-cover crop example above, an objective based on that question might look like this: *My objective is to determine if a legume cover crop will supply enough nitrogen to meet the needs of my subsequent cash crop.*

If you are having trouble articulating your research question or objective, talk to other farmers or an agricultural advisor to help clarify your thinking. Again, keep it simple: The simpler the research question, the simpler the project will be to conduct.

STEP 2: Develop a research hypothesis. Your research hypothesis stems directly from the research question or objective. A hypothesis is simply a clear statement of what you expect the outcome of your experiment to be, based on the limited evidence you have at hand. A well-written hypothesis statement can be confirmed (or denied) with actual data. In fact, the hypothesis gives an indication of what will actually be measured in the experiment. A well-developed hypothesis will help you obtain the most useful and practical information for the time and resources you invest in your research project. Possible hypothesis statements for the research questions outlined above are summarized in Table 1.

STEP 3: Decide what you will measure and what data you will collect. The next step in planning your on-farm research project is to determine the data you will be collecting. Your research hypothesis should give you a general idea, but now is the time to be specific: What will you measure and record in order to answer your question and test the validity of your hypothesis? This is also the time to decide what techniques you will use to get your data, looking at factors such as cost, practicality and feasibility.

In many crop research projects you will be collecting yield data, but depending on your project, you might also be collecting data on soil nutrient levels, crop development, plant health, plant height, leaf number, chlorophyll content, pest numbers, yield quality parameters (e.g., protein, Brix levels, fruit size, insect damage, moisture, etc.), costs or anything else you want to know about. The key determinant in deciding what to measure is whether the information will be useful in answering your research question.

Drawing Conclusions

Be careful about drawing too many conclusions from your data, particularly about the relationship between various effects that you observe. For example, if you planted a cover crop and found that it provided both improved weed control and higher yield, you cannot conclude that the higher yield was caused by the reduction in weeds. Like many practices, a cover crop will cause many changes that can influence yield, ones that you may not be measuring in your research.

Say, for example, you are looking at whether a higher planting density reduces weed competition in the field. Once you have your treatments defined (i.e., narrower row spacing and/or more plants within the row), you will need to decide what you will measure as an indicator of weed competition. Some possible options include percent weed cover at specific time intervals during the growing season, or the weight of weed biomass. You might also measure the effect of higher planting density on both weed density and final crop yield. Remember that each variable you decide to measure will come with its own time commitment in data collection and analysis, and may incur costs.

STEP 4: Develop an experimental design. It is tempting to rush through the previous steps and start planning what the experiment will look like in the field. But the task of designing your experiment should flow from the previous steps. Experimental design includes arranging treatments in the field so that error and bias are reduced, and data can be accurately analyzed using statistics. Experimental design and statistical analysis (step 9) go hand in hand: If an experiment has a poor design, you cannot have confidence in the data. For example, see the profile of farmer Steve Groff, who studied grafting to control disease in high tunnel tomatoes. In the first year, a mistake was made in the experimental design that prevented him from addressing some of his research questions, and the mistake was corrected for the second year.

There are several standard experimental design layouts used in on-farm research. Which one you choose will be based primarily on the number of treatments you are investigating. You can explore experimental design concepts and techniques in more detail in the next section, Basics of Experimental Design. If possible, plan your experiment for at least two growing seasons to increase the reliability of your results.

STEP 5: Choose the location and map out your field plots. After you have figured out your experimental design, you are ready to choose a location and design your field setup. You should be specific about plot size and layout, how the crop will be planted, which treatments are to be applied in each plot, and any other important aspects of managing the plots. Some guiding principles to help site your project:

- Select a field that has the right characteristics for what you are testing. Look at the field history and make sure there are no major problems that might prevent you from establishing the plots, or that could negate your results.
- Research plots should be accessible and easy to maintain. To facilitate management, for example, you may want to set up plots that run the length of the field and are wide enough for one or two tractor passes. It should be located close to the home farm so you can make observations regularly.
- Each treatment plot should be large enough to collect the data you need. If you can, separate your treatments with buffers to reduce cross-contamination.
- To moderate the effect of external variation, choose an area that is as uniform as possible in terms of soil characteristics, management history or slope, to name a few important types of variation.
- If there is some variation in the field that cannot be avoided, such as slope, drainage or soil type, try to set up your plots so that they are as uniform as possible with respect to field conditions. Since it is not always possible to achieve this, you can use blocking, replication and randomization to separate out the effect of field variability from the actual treatment effects. More information on these techniques is provided in the next section, Basics of Experimental Design.
- Keep in mind that land adjacent to the research plots can also have an impact on your research due to runoff, pesticide drift or by harboring pests that migrate into the research plots. This is potentially another source of external variation. To control these effects, establish a border or buffer zone around the entire research project. Ideally, a buffer should be a minimum of one tractor pass on all sides, or larger if conditions permit. Your technical advisor can help you determine what is most appropriate for your particular project.
- Last, create a detailed plot map for your chosen location based on your research design.

See Figures 3 and 4 for examples of plot maps that incorporate these principles.

STEP 6: Implement the project. Now that you are ready to implement the project, begin by establishing the research plots based on the map you created. Measure and mark your plots with clearly visible stakes or flags. In order to prevent mishaps with the project, make sure you discuss plot design, location, timeframe (one year or multi-year) and implementation with your entire farm crew, and share the detailed plot map with everyone involved.

Throughout the experiment, be careful to manage all plots *exactly the same*, except for the treatments (the practices you are testing or comparing.) For example, if your experiment is a comparison of two different varieties of tomatoes, plant all the plots on the same day using exactly the same planting technique, make the same number of passes with the tractor on all plots, cultivate all the plots in the same way and use the same pest control techniques in all plots. Follow this same principle when you set up your treatments. If you are comparing fertilizer treatments, for example, set the equipment for the first application rate and fertilize all the plots that are to receive that rate at the same time. Then change the setting for your second application rate and do all the plots assigned to receive that rate, and so on. The goal is to standardize as much as possible the techniques by which all field work is done. If possible, have the same group of people involved throughout the project so that there is consistency in how the plots are managed.

> Remember to keep all treatments and plots separate! Do not lump data together thinking that you will be able to just take an average. Doing so will invalidate your data.

Most importantly, *plan ahead* and *communicate*. Before you start any field work, create a management plan and calendar

for the project. Be specific about how the plots and the crop will be managed, how and when treatments are to be applied, and what data will be collected and how. Then make sure you review this plan with everyone who will be involved in the project. Good planning and communication can help ensure that the project is implemented correctly, that the work is done on time, and that you have the equipment and labor available when you need it.

STEP 7: Make observations and keep records throughout the season. Separate from your actual data collection (step 8), make observations and take notes throughout the season on influential factors such as rainfall, temperature, other weather events, seedling emergence, crop growth, soil condition, pest problems, field operations or anything else that seems relevant. Keeping a designated notebook, file or spreadsheet with this information will help you interpret your data and put your research results in context. In some cases, your observations will apply to the entire experiment: "Plants in all plots appear to be suffering from the extended dry period." In others, you may want to record observations about specific plots or treatments: "Plants in treatment A appear taller than treatment B." If you notice such differences between treatments, you may decide to measure those differences, even if you did not plan to do so originally.

STEP 8: Collect research data. For successful data collection:

- Be highly organized and specify your data collection techniques ahead of time.
- Prepare your data record sheets beforehand and have all your copies ready to fill out.
- If you are collecting samples, have all your bags or containers labeled accurately and organized by treatment and plot to facilitate the process.
- Remember to keep all treatments and plots separate! Do not lump data together thinking that you will be able to just take an average. Doing so will invalidate your data.
- If you are measuring yield, try to harvest from the center of the plots for your research data and, again, keep each treatment and plot separate. You will eventually harvest the whole area, but do not include buffer rows in your data.
- If you are measuring other effects (e.g., soil characteristics, weed cover, disease or insect damage, etc.), use random sampling procedures.
- Allow adequate time for sampling. For instance, expect plant sampling in 12 experimental units to take at least four hours; collecting soil samples will likely take longer.

STEP 9: Analyze data. Statistics are the most common tool used to determine if any differences observed in the treatments or comparisons are truly a result of the change in practice or merely a result of chance, due to natural variation. The statistical techniques that you will use to analyze your data depend on the research design you have used. You can learn to do your own data analysis, either by hand or with a statistical software program. In most situations, you will also want to consult with your technical advisor or Cooperative Extension personnel for guidance and assistance with your data analysis. The most common designs and statistical tests for on-farm research are discussed in more detail in the Experimental Design and Statistical Analysis sections.

STEP 10: Interpret the data and draw conclusions. Now that you have analyzed the data from your on-farm research, what do the results tell you? What can you infer from the data, and how can you apply that information to your farm? The statistical analysis you use will indicate whether or not there is a real or "significant" difference in the treatments, practices or varieties you are comparing. If there is a difference, and you feel confident about the results, you may decide to begin making changes in your farming practices.

But before you proceed, first discuss your results with your management team, other farmers or Cooperative Extension staff; it is always good to get a second opinion. Even then, you may still want to repeat the study for a second or third year to confirm the results and enhance the reliability of the data. If you are not sure of the results, or if the data seems off base, then you will need to dig deeper to determine what might explain the findings. Refer back to the observations and notes you made throughout the season (step 7). Was there some kind of environmental effect you did not anticipate? Did rainfall or temperature patterns over the course of the experiment influence the outcome? Was there a problem with how the plots were managed or in how the treatments were applied? Again, discuss your thinking with others before you decide how to proceed. Most important in this final stage of your project is to be objective and to be careful about making major changes in your management until you have accurate and reliable information.

Hold a Field Day to Share Your Results

Whatever questions prompted you to engage in on-farm research, it is likely that other farmers and ranchers in your community will have the same questions. Sharing your research results, particularly if they have the potential to improve your operation's sustainability, may inspire others to make similar changes and try new practices, which allows you to provide an important service to your community. Field days, including hands-on activities and demonstrations, are among producers' most preferred ways of learning new methods and practices.

If you find that organizing a field day is time consuming, check out SARE's Farmer Field Day Toolkit, a comprehensive online resource with tips and tools to help you organize a successful field day. Resources include a planning checklist, schedule of tasks, field sign templates, a sample press release and more. Visit www.sare.org/farmer-to-farmer.

PROFILE Steve Groff, Cedar Meadow Farm

Steve Groff used on-farm research methods to evaluate tomato grafting as an alternative to fumigation for the disease Verticillium wilt. Although he encountered challenges in designing his research, he eventually found that grafted plants (left) produced better yields than non-grafted, fumigated plants (right). *Photos by Steve Groff*

Tomato Grafting for Management of Verticillium Wilt in High Tunnels

Note: This profile presents a true example of the kinds of problems that can arise in an on-farm research project. In this case, plots were not established correctly in year one, so while the generated data was sound, it was limited in its application. Good communication between the farmer and technical advisor helped reset the direction of the project in year two, and ultimately helped the farmer answer his questions regarding tomato production in high tunnels.

Steve Groff's 225 acres at Cedar Meadow Farm in Lancaster County, Penn., includes two acres of multi-bay high tunnels, which help extend the growing season for a variety of vegetable crops. The high tunnels are quite productive, but Verticillium wilt, a disease caused by a soil-dwelling fungus, can become a significant problem in tomatoes. In an effort to explore alternative options to chemical fumigation, Groff developed an on-farm research project investigating the efficacy of grafted tomatoes to manage the disease.

Research Questions/Objectives

To help focus his research project, Groff came up with three questions:

- Does grafting with vigorous rootstock help tomatoes grown in high tunnels tolerate Verticillium wilt?
- What is the optimum plant spacing for managing grafted tomatoes to increase per plant productivity and help mitigate the added cost of grafted transplants?
- Can grafting be utilized as an alternative to soil fumigants for managing Verticillium wilt?

After reviewing research from North Carolina State University (NCSU), which showed that fruit yield of grafted plants in non-fumigated soil was similar to non-grafted plants grown in fumigated soil, Groff arrived at the following research hypothesis: Under high tunnel production where Verticillium wilt is present, grafted tomatoes will have better yields than non-grafted tomatoes.

Experimental Design

The research was conducted over two years, in 2008 and 2009. In the first year, prior to consulting his technical advisor, Groff set up two rows with the intention of answering the three research questions outlined above. He divided each row into four replications (blocks), with the treatment (plant spacing) and sub-treatment (grafted versus non-grafted tomatoes) completely randomized within each replication. However, he fumigated one whole row and left the other row un-fumigated. Because fumigation was not applied randomly to the individual replications in both rows, Groff could not conclusively determine whether it had a signification effect on the presence of Verticillium wilt. In order to account for any bias caused by the rows (e.g., location, irrigation issues, etc.), the fumigation treatment should have been applied randomly to both rows. So in 2008, although Groff ended up with valuable information about grafting and plant spacing, he did not properly address the question of whether grafting can be used as an alternative to fumigation.

FIGURE 1. 2009 Trial

ROW 1			
PLOT ID	MAIN PLOT	SUB-PLOT	REP
1	Fumigated	Grafted	Rep 1
2		Non-grafted	
3	Non-fumigated	Grafted	
4		Non-grafted	
5	Non-fumigated	Non-grafted	Rep 2
6		Grafted	
7	Fumigated	Grafted	
8		Non-grafted	
9	Non-fumigated	Non-grafted	Rep 3
10		Grafted	
11	Fumigated	Non-grafted	
12		Grafted	

ROW 2			
PLOT ID	MAIN PLOT	SUB-PLOT	REP
13	Non-fumigated	Non-grafted	Rep 1
14		Grafted	
15	Fumigated	Grafted	
16		Non-grafted	
17	Fumigated	Grafted	Rep 2
18		Non-grafted	
19	Non-fumigated	Grafted	
20		Non-grafted	
21	Non-fumigated	Grafted	Rep 3
22		Non-grafted	
23	Fumigated	Non-grafted	
24		Grafted	

In the second year, Steve Groff conducted the trial whereby the fumigant treatments were randomly assigned across both rows. This allowed him and his technical advisor to look for statistical "interaction" between grafting and fumigant treatment, which provides proper experimental data and analysis as to whether or not grafting is an alternative to fumigants.

After consulting with his technical advisor, Groff was able to fumigate sections of both rows in order to follow proper experimental design for 2009 (Figure 1). In both years, a split-plot (randomized complete block) design was used to test the hypothesis and answer the research questions. Groff started with two 300-foot rows within the high tunnel. Then, the main plots (plant spacing in 2008 and fumigated versus non-fumigated in 2009) were assigned to the rows. Both grafted and non-grafted tomatoes were planted in each main plot and were the sub-plot treatments. To evaluate the effect of the treatments, Groff measured the following: 1) marketable fruit number, 2) marketable fruit weight and 3) disease incidence using a scale developed by his technical advisor. Plant samples were also collected at final harvest to verify that *Verticillium dahliae* was present within symptomatic plants. All tomatoes were planted at the same time and managed in the same way throughout the growing season.

Statistical Analysis and Findings

A split-plot factorial ANOVA and an LSD test were used to evaluate the field data. Based on the results of Verticillium wilt incidence and marketable fruit weight, fumigation did not have an apparent impact on crop yield. Therefore, the results of the fumigated and un-fumigated experiments were combined in 2008 to illustrate main effects of grafting and plant spacing. The data shows that the grafted plants produced significantly more fruit yield through increased fruit size and number (with 99 percent confidence). Furthermore, crop productivity per acre was maintained even as plant spacing increased. Because the impact of fumigation could not be assessed in the 2008 study, Groff was not able to determine if the yield increases seen as a result of grafting were directly attributed to tolerance of Verticillium wilt. However, they did show that even under severe disease pressure, the grafted plants performed very well. The results from 2009 showed that grafted plants responded differently to fumigation than non-grafts, therefore supporting the hypothesis that the grafted plants had tolerance to this devastating disease. Based on the results of this project, Groff expanded the use of grafted tomato transplants from 500 plants to 8,000 plants in the next season, and continues to utilize grafted plants in his tunnels today.

Project Team

Groff received technical assistance as well as plant material for this project from Cary Rivard, who at the time was a graduate research assistant working with NCSU professor Frank Louws. Rivard coordinated transplant production, experimental design, data collection and statistical analysis. To learn more about this project, including an analysis of the data, visit www.sare.org/project-reports and search for project FNE08-636.

LEARN MORE

Read the SARE fact sheet, *Tomato Grafting for Disease Resistance and Increased Productivity*, at www.sare.org/tomato-grafting.

Profile written by Cary Rivard, Kansas State University.

Basics of Experimental Design

The previous section summarized the 10 steps for developing and implementing an on-farm research project. In steps 1 through 3, you wrote out your research question and objective, developed a hypothesis, and figured out what you will observe and measure in the field. Now you are ready to actually design the experiment. This section provides more detail on step 4 in the process.

Recall from the introduction that on-farm research provides a way of dealing with the problem of field and environmental variability. In comparing the effects of different practices (treatments), you need to know if the effects that you observe in the crop or in the field are simply a product of the natural variation that occurs in every ecological system, or whether those changes are truly a result of the new practices that you have implemented.

With the right experimental design and statistical analysis, you can identify and isolate the effects of natural variation and determine whether the differences between treatments are "real," within certain levels of probability.

Take the simple example of comparing two varieties of tomatoes: a standard variety and a new one that you have just heard about. You could plant half of a field in the standard variety and the other half of the field in the new variety. You plant the tomatoes on exactly the same day, and you manage both halves of the field exactly the same throughout the growing season. Throughout the harvest period, you keep separate records of the yield from each half of the field so that at the end of the season you have the total yield for each variety. Suppose that under this scenario, the new variety had a 15 percent higher yield than your standard variety. Can you say for sure that the new variety outperforms your standard variety? The answer is no, because there may be other factors that led to the difference in yield, including:

- The new variety was planted in a part of the field that had better soil.
- One end of the field was wetter than the other and some of the tomatoes were infected with powdery mildew.
- Soil texture differences resulted in increased soil moisture from one end of the field to the other.
- Part of the field with the standard variety receives afternoon shade from an adjacent line of trees.
- Weed pressure is greater in one part of the field with the standard variety.
- Adjacent forest or wildlands are a source of pests that affect one end of the field more than the other.

Because the experiment was not set up to account for field variability, you cannot conclude whether one variety's superior performance was due to the variety itself or due to differences in growing conditions. You did not replicate the treatments. Therefore you have no way to apply a statistical test of your data. As you think about your own farm, what other sources of variation might have an impact on your research question?

With the right experimental design and statistical analysis, you can identify and isolate the effects of natural variation and determine whether the differences between treatments are "real," within certain levels of probability. This section looks at three basic experimental design methods: the paired comparison, the randomized complete block and the split-plot design. Which one you choose depends largely on the research question that you are asking and the number of treatments in your experiment (Table 2).

The number of treatments in your experiment should be apparent from your research question and hypothesis. If that is not the case, then you will need to go back and refine your research question so that you have more clarity as to what you are testing. As previously noted, when identifying your research question (step 1), remember to keep things simple. Avoid over-complicating your experiment by trying to do too much at once. And, keep in mind that although the randomized complete block and split-plot designs provide more information than the paired comparison, they

TABLE 2. Three Experimental Design Methods

DESIGN METHOD	WHEN TO USE	STATISTICAL ANALYSIS
Paired comparison	To compare two treatments	t-test
Randomized complete block	To compare three or more treatments	Analysis of variance (ANOVA)
Split-plot	To see how different treatments interact	Analysis of variance (ANOVA)

Cornell Cooperative Extension researchers and an Interlaken, N.Y., farmer teamed up on a SARE-funded project to study the effect of plant and row spacing on bacterial rot incidence and onion yield. The project used a randomized complete block design with five treatments and four replications, where each replicate was one bed wide. *Photo Courtesy Cornell Cooperative Extension*

also require a larger field area, more management and more sophisticated statistics to analyze the data. Table 2 also lists the type of statistical analysis associated with each experimental design method. These statistical techniques are covered in the next section, Basic Statistical Analysis for On-Farm Research. First is a review of some basic experimental design terminology.

Treatments: A treatment is the production practice that you are evaluating. Examples of treatments include choice of variety, different fertilizer rates, different fertilizer timing, choice of cover crops, different cover crop management strategies, timing of planting, type of tillage, different pest control methods or different irrigation strategies. For animal operations, treatments might be different feed rations, type of bedding, pasture versus confinement, grazing period, nutritional supplements, or disease/parasite controls. The choices are limitless given the complexity of farming. On-farm research usually compares just two or three practices. In most cases, one of the treatments is the standard practice, or what you usually do, and is known as the "control."

Variable: In statistics, a variable is any property or characteristic that can be manipulated, measured or counted. In on-farm research, the independent variable is the different treatments (practices) you are applying, and the dependent variable is the effect or outcome you are measuring. What you measure in your particular experiment depends on what treatments you apply. Examples include crop yield, weed density, milk production or animal weight gain.

Plot: Plots are the basic units of a field research project—the specific-sized areas in which each treatment is applied.

Replication: Replication means repeating individual treatment plots within the field research area. If you set up an experiment comparing two treatments, instead of setting out just one plot of Treatment A and one plot of Treatment B, you repeat the plots within the field multiple times. Replications reduce experimental error and increase the power of the statistics used to analyze data.

Block: It is usually not possible to find a perfectly uniform field in which to conduct the experiment, and some sources of variation simply cannot be controlled (e.g., slope or soil texture gradients). In order to address the problem of field variability, divide your field of interest into sections

FIGURE 2: Addressing Field Variability with Blocking

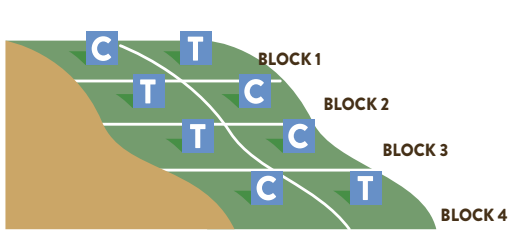


FIGURE 2a

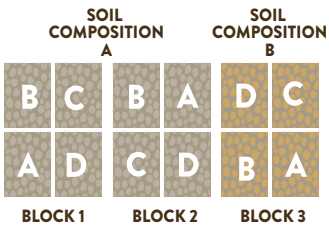


FIGURE 2b

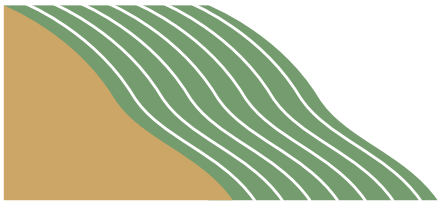
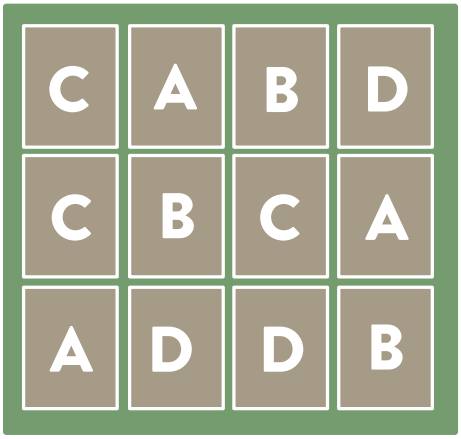


FIGURE 2c

Agricultural research should usually be blocked because of field variability. If your field has a known gradient, such as a fertility or moisture gradient, it is best to place blocks so that conditions are as uniform as possible within each block. Figure 2a: On a slope, for example, each whole block should occupy about the same elevation. Treatments are randomized and run across the slope within each block. Figure 2b. Place whole blocks within different soil types. Figure 2c: If blocks cannot be used to account for variability, then each treatment should run across the whole gradient, as in all the way down the slope or all the way across the field. This arrangement can also be used for a completely randomized design (see Figure 3).

FIGURE 3. Completely Randomized Design



The completely randomized design works best in tightly controlled situations and very uniform conditions. A farmer wants to study the effects of four different fertilizers (A, B, C, D) on corn productivity. Three replicates of each treatment are assigned randomly to 12 plots.

that have common slope and soil characteristics. Within each section—typically known as blocks—field conditions should be as uniform as possible. Taken together, however, all of your blocks should encompass the variability that exists across the research area. After delineating the areas for your blocks, make sure you include each treatment inside each block; that way, your blocks can serve as replications. In most on-farm research studies, four to six blocks are sufficient to provide a good level of confidence in the results. Figure 2 provides examples of how to use blocking to address field variability due to slope or soil type.

Randomization: In addition to replication, randomization is also important for addressing the problem of field variability, reducing experimental error and determining the true effect of the treatments you are comparing. Replications should be arranged randomly within the field. Or in the case of a blocked experimental design, treatment plots must be arranged randomly within each block. If you have three treatments, for example, you cannot place those treatments in the same left-to-right sequence within each block. They must be arranged in a random order. This can be done using the flip of a coin, drawing numbers from a hat or using a random number generator for each block.

Common Research Designs for Farmers

Completely Randomized Design

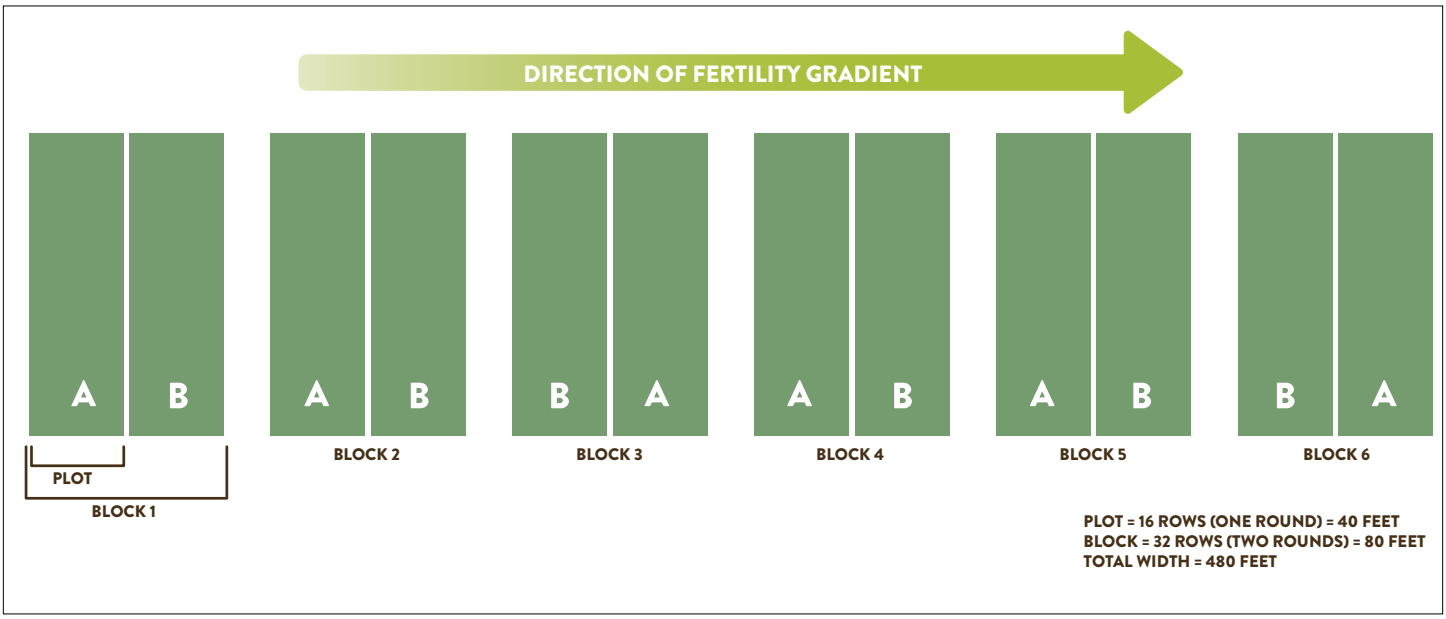
The simplest experimental layout is a completely randomized design (Figure 3). This layout works best in tightly controlled situations and very uniform conditions. For this reason, the completely randomized design is not commonly used in field experiments. You can use it if you are working with a very uniform field, in a greenhouse or growth chamber, or if you have no idea about the variability in your field. The statistical analysis of completely randomized designs is not covered in this publication.

Paired Comparison

As the name implies, the paired comparison is used to compare the effect of two different treatments assigned randomly within blocks. Each block contains two plots—one plot of each treatment—and blocks are replicated four to six times across the field. Typically, plots run the length of the field and are one or two tractor widths in order to facilitate management. Figure 4 shows the layout for a typical paired comparison experiment.

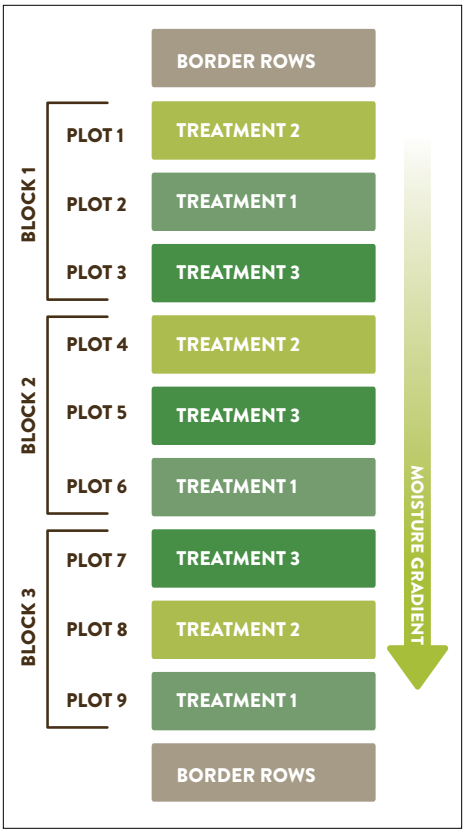
In collecting yield data or other samples from the field, measurements are generally taken from the center rows of a plot in order to avoid any "edge effects." You can use this design to evaluate any pair of treatments: comparing two varieties, growing the crop with and without starter fertilizer, comparing two rates of fertilizer application, comparing the timing of nu-

FIGURE 4. Paired Comparison Experimental Design



The paired comparison is used to study two treatments. Each treatments should still be replicated several times, generally in blocks that should be set up to account for any known field variability. Randomize treatments within each block. Harvest only the middle rows of each plot (e.g., eight middle rows). Adapted from Anderson (1993).

FIGURE 5. Randomized Complete Block Experimental Design



A randomized complete block experiment. Adapted from Nielsen (2010).

trient application, or using two different cover crop treatments, for example. The paired comparison is a type of randomized block design, but it is usually classified on its own since we use a simplified statistical analysis, the t-test, to analyze the data when compared to the standard randomized complete block design (described next). The t-test will help you determine whether the difference you observe in two treatments is due to natural variation or is a real difference. It is described in the section, Using the t-Test to Compare Two Treatments.

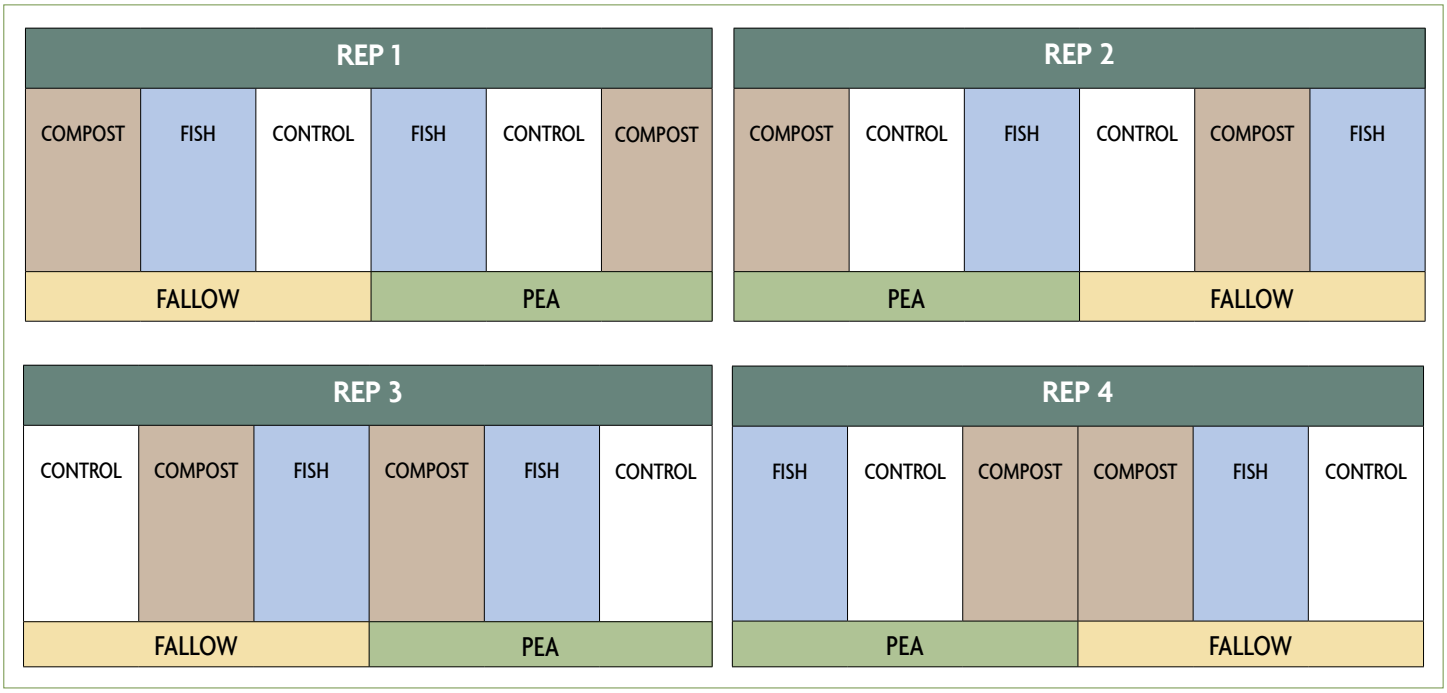
Randomized Complete Block

The randomized complete block design is used to evaluate three or more treatments. As with the paired comparison, blocking and the orientation of plots helps to address the problem of field variability as described earlier (Figure 3). Each block contains a complete set of treatments, and the treatments are randomized within each block. Four to six replications of a "complete block" are sufficient for most on-farm research projects. Figure 5 shows a schematic of a randomized complete block design with three treatments. The statistical test known as analysis of variance (ANOVA) is used to analyze the data from a randomized complete block experiment.

Split-Plot

The split-plot design is for experiments that look at how different sets of treatments interact with each other. It is also used when one of the treatment factors needs more replication or when it is difficult to change the level of one of the factors. For example, in a cover crop study, it may be most convenient due to machinery limitations to plant cover crops in larger areas (the main plots) and then impose other treatments such as fertilizer rates in the sub-plots. In this design, main treatments are overlaid with another set of sub-treatments. Though fairly easy to set up in the field, a split-plot experiment will usually take up a larger area and be more complex to implement, manage and analyze. Given the greater number of treatments and the interaction component, using ANOVA for the split-plot design is also more complex than with the paired comparison or the randomized complete block. It is best to work with someone who has expertise in this type of research design when setting up a split-plot experiment. An example of a split-plot design is shown in Figure 6.

FIGURE 6. Split-Plot Experimental Design



In split-plot design, one treatment (the main plot—fallow or pea) is split further into another treatment (sub-plots) of interest. Here, compost and fish fertilizer are compared to a no-treatment control. Main plots are sometimes decided by field machinery limitations, such as the pea planter used to plant a larger area, with compost and fish emulsion applied to smaller areas. Adapted from Sooby (2001).

Basic Statistical Analysis for On-Farm Research

Statistical analysis involves a sequence of mathematical computations for comparing treatments and evaluating whether any observed differences are truly a result of the change in practices, or if the differences may be due to chance and natural variation.

This section looks at statistical analysis in more detail, expanding on step 9 in the process outlined earlier. Recall that the type of statistics you use to analyze your data follows directly from your experimental design (Table 2). The two types of statistical analysis covered here are the t-test and ANOVA. You can learn to do your own data analysis either by hand or using a statistical software program. In most situations, you will also want to consult with your agricultural advisor or Cooperative Extension personnel for guidance and assistance with your data analysis. Before we get into the specifics of those techniques, here is a review of some basic statistics terminology:

Normal distribution: The normal distribution describes a collection of data organized around an average value (the mean), with greater or lesser data points distributed approximately equally on either side of that value. The data in a normal distribution is often described as following a bell-shaped curve (Figure 7). This phenomenon occurs regularly in nature and is the basis for the statistics we use in on-farm research. Using an agricultural example, if you recorded the average corn yield from all the farmers in a given area, those yields would probably follow a normal distribution. The key features of the normal distribution are the mean, or average value, and the variance, or how widely the data is spread around the mean.

Mean: The mean is the average value in a data set. You calculate the mean by adding up all the data points in the group and then dividing the total by the number of data points.

Variance: The variance in a collection of data describes the extent to which the high and low values differ from the mean value. Figure 7b shows three normal distribution curves with different variances.

Standard deviation: The standard deviation, which is the square root of the variance, is more typically used to analyze how your data varies from the mean. A small standard deviation means that the data is clustered closely around the mean; a large standard deviation means the data is spread out over a wider range of values. The standard deviation is expressed in the same units as the data (e.g., bushels per acre).

Standard error: This term usually refers to the "standard error of the mean." In statistical analysis you often want to know how representative a certain sample size is of the overall population. When you collect samples and calculate a mean, this data presents a snapshot of the system you are studying but it is not an exact representation because there is data that you did not collect. If you were to repeat your sampling procedure, or collect more or fewer samples, you would get somewhat different data with a different mean. So, calculating standard error is a way of estimating how representative your data actually is of the population within the system you are studying. The standard error is basically calculated as the standard deviation of the distribution of sample means taken from a population. The smaller the standard error, the more representative that sample is of the overall population. Also, as the number of samples you take to make the standard error calculation increases, the standard error decreases.

Error: In the analysis of research data, you may still come to the wrong conclusion. There are two kinds of errors in statistical analysis: a Type I error and a Type II error. A Type I error occurs when you identify a difference when in fact the treatments were not different. A Type II error is the opposite, when you determine there is no difference yet in fact there really is. A probability level, typically 5 percent in field research, is used to indicate the likelihood that a Type I or Type II error will occur. This concept is closely related to the concept of statistical significance, described next.

FIGURE 7. Normal Distributions

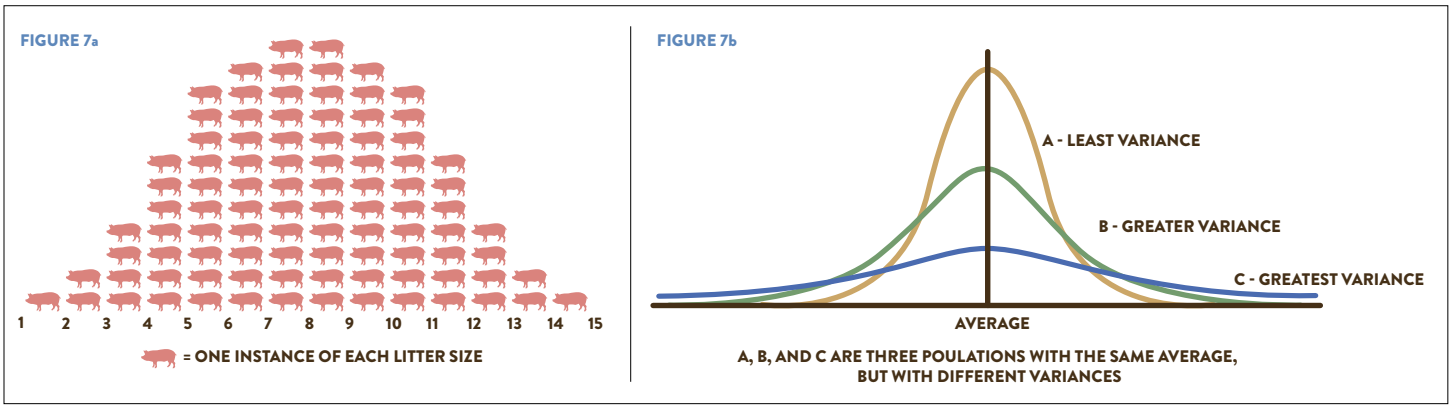


Figure 7a: Litter size in sows follows a normal distribution. The most frequent size is seven or eight pigs, and the frequency drops off as litter sizes move to the upper and lower extremes of two or 15 pigs. Adapted from Anderson (1993). Figure 7b: The distribution curve can be narrow or wide, based on the amount of variation (variance) in the data. All three graphs represent normal distributions with the same mean (average) value.

FIGURE 8. Statistical Significance in Yield Data Comparing Three Treatments

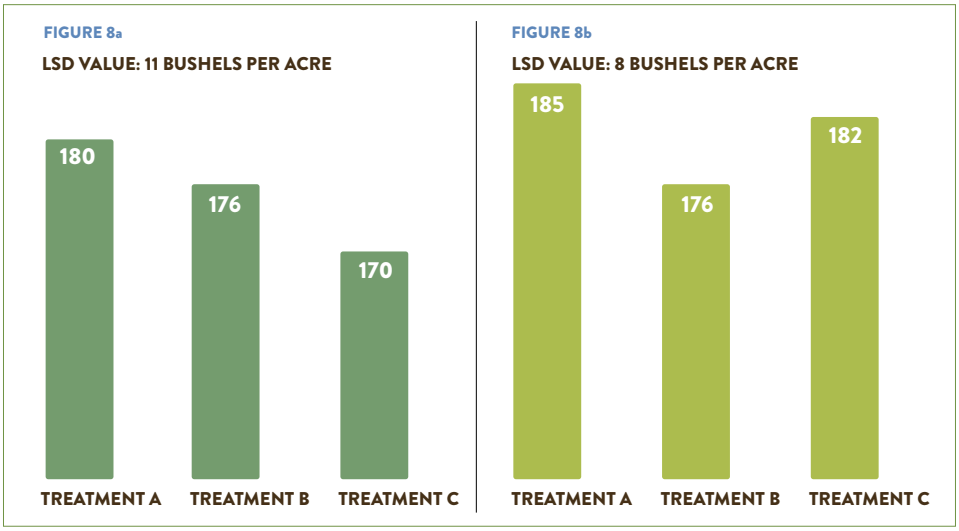


Figure 8a: The least significant difference (LSD) value calculated from the statistical analysis of the data was 11 bushels per acre. None of the pairs of treatment means differ by more than this LSD value, so the appropriate conclusion is that 1) the treatment effects on yield were similar, 2) the observed differences are likely due simply to random chance or background "noise," and 3) the apparent trends in treatment yields (A>B>C) would likely not be repeated in subsequent trials comparing these same treatments. Figure 8b: In this example, the LSD value is 8 bushels per acre. Based on that LSD value, you can confidently conclude that Treatment A significantly out-yielded Treatment B and will likely do so again in future field trials, but was statistically similar to Treatment C. Treatment C was also statistically similar to Treatment B.

Statistical significance/Least significant difference: In statistics, significance of results does not refer to how important those results are. Rather, a statistically significant finding means that the researcher is confident that the result is reliable within certain parameters. In other words, the treatment had an actual effect on the system, and the results were not the product of chance. This concept is captured by a numerical value known as the least significant difference (LSD). Any difference between treatment practices that is greater than the LSD value means the difference you identified is most probably a result of the treatment, whereas a smaller difference is likely to be the result of chance—you cannot guarantee the same results if you repeated the experiment. The least significant difference is always noted at a certain confidence level, usually 90 or 95 percent, which tells you the probability that a Type I error could occur. For example, a 90 percent confidence level means there is still a 10 percent chance the difference was actually due to natural variation. Sometimes you will see the confidence level identified by its corresponding alpha value: A 95 percent confidence level has an alpha of 5 percent (LSD 0.05) and a 90 percent confidence level has an alpha of 10 percent (LSD 0.1). Anything less than 90 percent certainty is usually not considered scientifically valid. This concept is crucial to understanding and interpreting your results, so more information is provided in the calculations that follow.

Sum of squares: This is a measure of variation or deviation from the mean (average). It is calculated by finding the difference between each individual data point and the mean of all the data points, then squaring each difference and adding all the squared values.

Stats for a Paired Comparison Design

See the section Using the t-Test to Compare Two Treatments beginning on page 18 for step-by-step instructions on statistical analysis of this kind of experiment.

Stats for Randomized Complete Block and Split-Plot Designs

For on-farm research projects comparing three or more treatments, a more complex analysis is required than the t-test. You could potentially compare your treatments two at a time using the t-test. For example, in an experiment with three treatments, you could calculate the LSD to compare treatment one and treatment two, two and three, and one and three. Note, however, that you normally would not calculate all of the possible comparisons because doing so will increase your chance of coming to a wrong conclusion. There is a statistical correction that needs to be made in this case. Similarly, in a split-plot experiment, a simple t-test can provide an LSD for comparing main treatments. But this can be quite cumbersome to do by hand, so we recommend using statistical software (see Resources). When discussing your project with your cooperating researcher or Extension agent, make sure to ask them about getting assistance with statistical analysis. See Figure 8 for an example of how the results of three treatments might relate to one another in terms of LSD.

Non-Parametric Statistics: What If My Data Does Not Follow a Normal Distribution?

Although most on-farm research deals with data that follows a roughly normal distribution, some types of field data are not normally distributed. For example, the distribution of agricultural pest populations in an orchard may not be spread uniformly across the field but rather occur in clumps, due to any number of influences. Other data that cannot be described by a normal distribution includes ranking data collected through surveys that assess a population's opinions or preferences.

Statistical methods that deal with this kind of data are called non-parametric statistics. Since non-parametric methods are less dependent on how the data is distributed, they can have broader applicability. Also, non-parametric tests are often simpler than corresponding parametric statistics and can be applied when less is known about the population (data) in question. Despite these advantages, knowing which parametric tests to use, and under what circumstances, requires knowledge and expertise. See the profile of farmer Clarissa Mathews, who collected data on the effectiveness of trap crops and pheromone traps to control brown marmorated stink bugs in vegetable plots. After collecting her data, she checked it for a normal distribution before determining which method of statistical analysis to use. Check with your cooperating researcher or Extension agent for information and assistance.

Using the t-Test to Compare Two Treatments

The following is adapted and reprinted from A Field Guide for On-Farm Research Experiments (March 2004). Keith R. Baldwin, Ph.D. Horticulture Specialist. Cooperative Extension Program at North Carolina A&T State University, Greensboro, North Carolina. Used by permission.

To evaluate the statistics for a paired comparison, you will need a calculator that can give you the square root of a number. Or, most spreadsheet programs can perform these statistical calculations for you after you enter your data into the spreadsheet. *Our objective here is to calculate the least significant difference between the two treatments.*

Recall that four to six replications of the treatment comparisons are usually recommended in on-farm experiments to account for field variation and the effect of chance. The following steps describe how to calculate the least significant difference for a blocked paired comparison experiment with six replications. Refer to Table 3 as you read through the instructions.

TABLE 3. Sample Data Table for Paired Comparison Statistical Analysis

BLOCK/ REP	COLUMN 1 Treatment 1 data	COLUMN 2 Treatment 2 data	COLUMN 3 Difference Column 1 - Column 2	COLUMN 4 Average Difference	COLUMN 5 Deviation Column 3 - Column 4	COLUMN 6 Deviation squared Column 5 x Column 5
1				d		
2				d		
3				d		
4				d		
5				d		
6				d		
TOTALS						TOTAL
AVERAGE			d			

Begin by filling in the data for each block.

1. Put the data (for example, yield) for Treatment 1 in Column 1.
2. Put the data for Treatment 2 in Column 2.
3. In Column 3, subtract the number in Column 2 from the number in Column 1. (Some numbers in Column 3 may be negative, which is completely normal.)
4. Calculate the average of each of the first three columns. You do this by adding up all the numbers in the column (positive and negative) and dividing by the total number of blocks (six in this case).
5. Copy the Column 3 average (labeled "d" in Table 3) into every row in Column 4. (This will be the same number in every row.)
6. In Column 5, subtract the number in Column 4 from the number in Column 3. Negative numbers can be tricky. Remember that (-5) - 5 = - 10. But also remember that subtracting a negative number is the same as adding it as a positive number. For example, (-5) - (-5) is the same as (-5) + 5, which equals 0.
7. In Column 6, square the number in Column 5 (multiply it by itself). Note that a negative number squared becomes a positive number. For example, (-10) x (-10) = 100.
8. Add all the numbers in Column 6. Record this value. In statistics, this is the *sum of squares*.
9. Subtract 1 from the number of blocks. Record this value. In this case, 6 blocks - 1 = 5. In statistics, this is the *degrees of freedom*.
10. Divide the sum of squares (from step 8) by the degrees of freedom (from step 9). Record this value. This is the *variance*.
11. Divide the variance (from step 10) by the number of blocks. Record this value. This is the *variance of the means*.
12. Take the square root of the variance of the means (from step 11). Record this value. This is the *standard error*.
13. Select the t-distribution critical value based on the number of blocks (replications) in the experiment and level of confidence you want in the statistics. The t-value is a predetermined value that can be found in Table 4. Multiply the standard error (from step 12) by the selected t-value. The product is the least significant difference, or LSD.

TABLE 4. T-Distribution Critical Values

NUMBER OF BLOCKS	DEGREES OF FREEDOM	T-VALUE FOR 90 PERCENT CONFIDENCE LEVEL	T-VALUE FOR 95 PERCENT CONFIDENCE LEVEL
4	3	2.35	3.18
5	4	2.13	2.78
6	5	2.02	2.57

Recall that the LSD tells us how large the difference between treatments needs to be to: 1) account for possible errors and random events, and 2) to provide a degree of certainty (90 percent or 95 percent, depending on which you choose) that the difference is real, or "significant." If the average difference between treatments (the bottom figure in Column 3 in Table 3) is smaller than the LSD, it is too small a difference to draw any conclusions from the experiment. If the average difference is greater than the LSD, then the treatments are significantly different at the selected confidence level, and conclusions about the treatments may be drawn.

A sample statistical calculation is shown in Table 5. In this hypothetical experiment, a grower wants to determine the effect of compost tea spray on strawberry yield. In a randomized and replicated experimental field (with buffer beds between treatment beds), she collects yield data from six beds that were sprayed with compost tea (Treatment 1) and six beds that were not sprayed with anything (Treatment 2).

TABLE 5. Sample Calculations for Hypothetical Paired Comparison Experiment

BLOCK/REP	COLUMN 1 **Treatment 1** compost tea sprayed strawberry yield (pounds)	COLUMN 2 **Treatment 2** no compost tea strawberry yield (pounds)	COLUMN 3 Column 1 - Column 2	COLUMN 4 Average difference	COLUMN 5 Column 3 - Column 4	COLUMN 6 Column 5 x Column 5
1	190	165	25	15	10	100
2	210	180	30	15	15	225
3	180	185	-5	15	-20	400
4	190	170	20	15	5	25
5	185	180	5	15	-10	100
6	195	180	15	15	0	0
TOTALS	1,150	1,060	90			850
AVERAGE	191.7	176.7	15			

Continuing with step 8 from the instructions:

- Add the numbers in Column 6. Sum of squares = 850.
- Subtract 1 from the number of blocks to get the degrees of freedom. 6 - 1 = 5.
- Divide 850 by the degrees of freedom to get the variance. 850/5 = 170.
- Divide 170 by the number blocks to get the variance of the means. 170/6 = 28.3.
- Calculate the square root of the variance of the means to get the standard error. √28.3 = 5.32.
- Multiply this answer by the selected t-value (step 13). In this case, the farmer wants to be 95 percent confident that her results are significant, so she chooses 2.57.

  5.32 x 2.57 = 13.67.

Finally, compare the average difference from Column 4 with the LSD. In this example, the farmer finds that the average difference of 15 is greater than the LSD of 13.67. The farmer concludes with confidence that the compost tea treatment increased yield. Using proper research design and statistics lets the farmer draw this conclusion even though in one paired comparison the yield in the untreated crop was greater.

Software programs are available that will do statistical calculations for you. Most spreadsheet programs can perform a simple statistical analysis after you type in your data. For more information, contact your technical advisor.

PROFILE Clarissa Mathews, Redbud Farm

Integrated Trap Crop and Pheromone Trap System for Organic Management of Brown Marmorated Stink Bug

Photo by Clarissa Mathews

Like many farmers in the United States, Clarissa Mathews is striving to manage the brown marmorated stink bug on her 50-acre farm in West Virginia. This stink bug feeds on a wide range of crops and has no native natural enemies, so the losses can be devastating. At Mathews' Redbud Farm, stink bugs go through two life cycles in a growing season, with as many as 10 adults per tomato fruit. Annual losses from stink bugs at Redbud Farm have exceeded 30 percent of total revenues. Stink bugs are a major challenge for growers, and researchers and growers alike are struggling to develop effective control measures, especially ones that are ecologically sound.

Research Question/Objectives

Mathews identified a non-chemical approach to managing stink bugs that she thought might work on her USDA-certified organic farm—one that combined a perimeter trap crop with commercially available pheromone traps. But before she could implement this idea across the entire farm, she first needed to test it. Her basic research question was, "Is the new stink bug management strategy effective and economically feasible?" Specific objectives for this on-farm research project were to:

- Evaluate the effectiveness of the trap crop system in protecting four cash crops (i.e., stink bug densities on the cash crops, stink bug damage levels and crop yields).
- Determine the relative suitability (i.e., attractiveness) of species studied as trap-crop plants (green amaranth and sunflowers).
- Determine if stink bugs display directionality with respect to colonization of the plots.
- Determine stink bugs' host-use preference with respect to the four cash crops studied.

Experimental Design

In 2012, Mathews evaluated the effectiveness of the "trap crop plus pheromone trap" technique in four cash crops with known susceptibility to stink bugs: okra, sweet peppers, tomatoes and summer squash. The research project used a randomized complete block design, with four blocks in two different fields. Each block consisted of two 900-square-foot plots: one with the trap crop and pheromone trap, and one plot without, to act as the control. Treatments were randomized within each block. Each plot consisted of four 36-foot rows, planted randomly to each of the four vegetable crops. For the treated plots, a trap crop of sunflowers and green amaranth was established in a 3-foot-wide perimeter around each plot, while stink bug traps baited with a chemical pheromone lure were placed on each of the four sides of the plot. All plots were planted at the same time and were

managed in the same way on the same schedule throughout the growing season.

A schematic of the experimental design is shown in Figure 9. To test the effectiveness of the new technique, Mathews measured the following over the course of the growing season:

- The number of stink bugs (adults and nymphs) and egg masses in each type of vegetable crop.
- The number of stink bugs captured in the pheromone traps within the trap crop perimeters.
- Plant damage and crop yields for each crop type once they reached maturity, noting salable versus unsalable portions of fruit. Yield data was totaled by crop type across the season.

Statistical Analysis and Findings

Mathews first checked to make sure the data followed a normal distribution. Once that was confirmed, she used separate ANOVAs to evaluate stink bug densities by crop type, seasonal stink bug densities, crop damage levels, crop yields and other effects. Results of the experiment showed that stink bugs were highly attracted to the sunflower trap crop, with more than a two-fold increase in average stink bug densities in the trap perimeters, as compared to the cash crops. The trap crop perimeters also delayed stink bugs' colonization of the cash crops, resulting in lower stink bug densities for tomatoes and peppers late in the season. However, reduced stink bug densities in the cash crops did not translate into significantly lower crop damage or higher yields in the trap crop plots as compared to control plots. Based on her results, Mathews concluded that the trap crop plus pheromone trap technique is effective for organic production, but will require a stink bug-specific pheromone lure or an organic mortality-inducing agent that can be incorporated within the trap crop perimeter in order to effectively reduce stink bug damage to the cash crops.

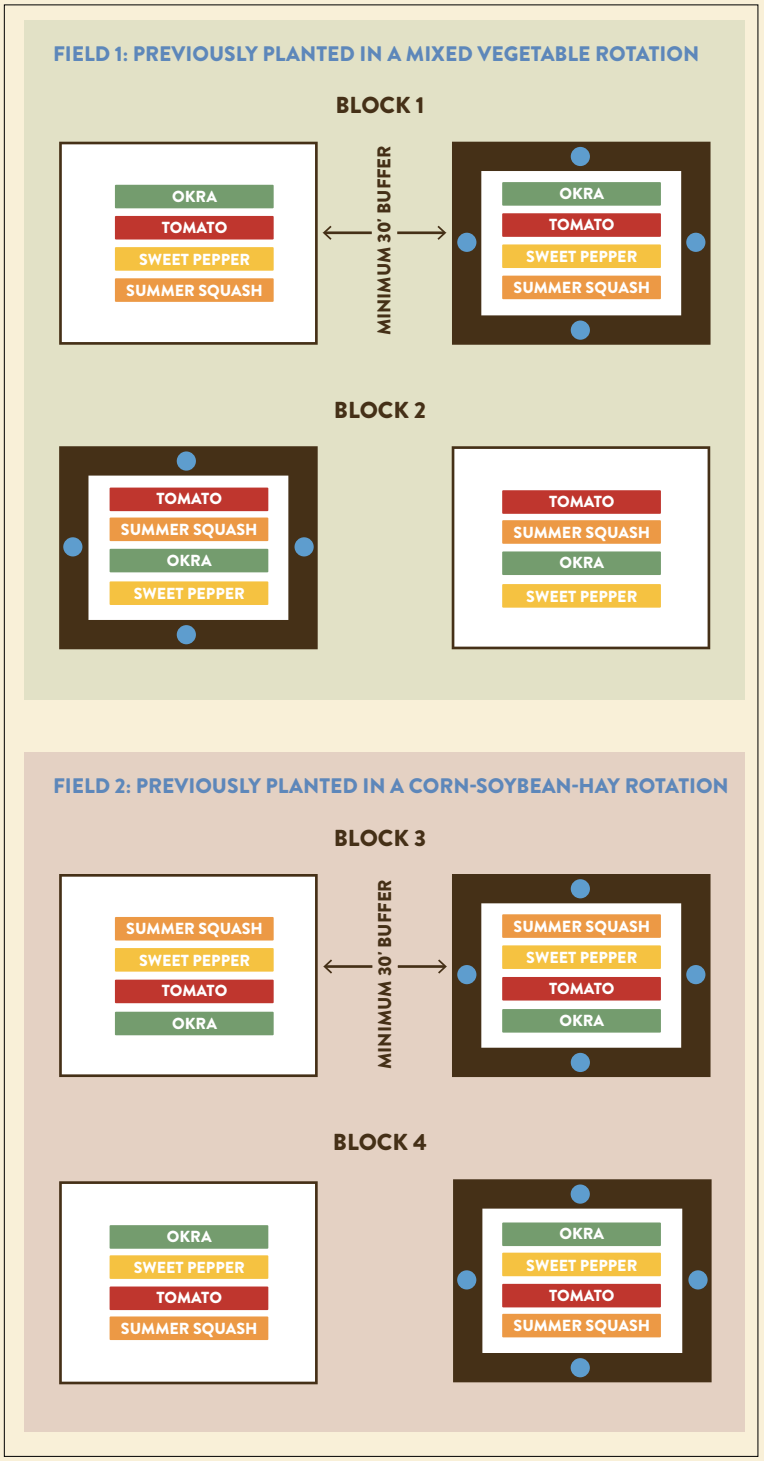
Project Team

Mathews has a doctorate in entomology from the University of Maryland, and her experience conducting field research projects is evident in this project. Farm manager Haroun Hallack is a former Extension agent in West Africa and has farmed organically for more than 15 years. Tracy Leskey, from the USDA Agricultural Research Service's Appalachian Fruit Research Station, provided additional guidance and support.

LEARN MORE

For a complete description of this project, with results and data analysis, visit www.sare.org/project-reports and search for project FNE12-759. Visit the Redbud Organic Farm website at www.redbudfarm.com.

FIGURE 9. Plot Layout for Redbud Farm Study of the Brown Marmorated Stink Bug, 2012.



The experimental design for this stink bug study included a control and a non-chemical treatment that combined a perimeter trap crop of sunflowers and green amaranth (brown border) with commercially available pheromone traps (blue dots). The experiment was planted into two fields with different cropping histories, and two whole blocks were placed into each field. Treatments were separated by a 30-foot buffer.

On-Farm Research for Pasture/Livestock Systems

Adapted from A Practical Guide to On-Farm Pasture Research. Bridgett Hilshey, Sidney Bosworth, Rachel Gilker. 2013. Published by University of Vermont and Northeast SARE. www.sare.org/practical-guide-to-on-farm-research

On-farm research in livestock and pasture-based systems poses unique challenges compared to crop research. Depending on your research question, you must carefully consider what the experimental unit is for the study. Is it an individual animal? Or is it a group of animals? And how many experimental units will you need?

University of Georgia Extension agents Randy Franks (left) and Mark Frye (right) collect samples of triticale on Jonny Harris' farm in Screven, Ga. Harris partnered with researchers to study the potential of forage cover crops to improve soil health and provide high-quality hay for livestock. *Photo by Candace Pollock, Southern SARE*

In either case, it can be difficult to hold management constant across treatment groups, and the livestock themselves add to the amount of variability that could affect the outcomes of the study. In addition, in pasture research you have to account for the diversity of plant species, changes in soil condition and topography, and grazing management variables. Also, as weather conditions change, pasture systems experience daily and seasonal fluctuations in growth rate and forage quality. In most pasture-based research, you cannot use a single measurement (such as yield or growth) at the end of one year to determine treatment effects. To accurately quantify the effect of changes in pasture condition on livestock, you need to know both the productivity and quality of a wide variety of grasses at multiple times throughout the year. As plants and soil within pastures tend to be highly variable, these measurements can be difficult to collect. However, this is commonly addressed by using "repeated measures," where the same measurement, such as weight gain or milk production, is taken repeatedly on the same animals over the course of the experiment.

Refer to the 10-step process outlined in the previous section, How to Develop an On-Farm Research Project, as your overall guide for developing a pasture-based research project. Also, see the profile of farmer Harry Cope for an example of how one person set up a research project to improve the forage quality of grazed corn by adjusting planting practices and interseeding a cover crop mix. In addition, the following suggestions can help ensure your livestock/pasture research gets you the information you need to make the best management decisions:

Formulating your research question. As with crop research, start with a clearly defined research question and objective. The research question should include information on exactly what the treatment will be, what you will measure to determine how effective the treatment is, and other useful details such as the start and end dates of the experiment. Examples of treatments in livestock/pasture projects include a certain fertilizer applied at a certain rate, a new plant species seeded into the pasture or a different feed ration. It is important to include a control group to contrast against the group receiving the experimental treatment.

Selecting the location. When choosing a research site, consider previous crop history (fertilizer rates, herbicides, tillage, etc.), drainage, forage species, soil texture, soil depth, topography, pest infestations and other factors. Choose a field site with the greatest possible uniformity. The goal is to plan and organize the field plot layout to assure that all treatments have an equal opportunity to succeed. For pasture research, you will want a fairly large tract of land, usually enough for at least six paddocks. The study will be easier if you use established, permanent paddocks, even if they are only permanent for the length of the project.

Developing a project timeline. Every research project is different and will require a different timeline. In general, most studies are conducted for at least two years. In pasture studies, you will likely collect data regarding the pasture and/or soil quality at multiple times during the year. That said, it is important to not overcommit yourself. Research can be very time consuming—for instance, expect sampling forage quality in 12 experimental units (six paddocks) to take at least 4 hours; collecting soil samples will likely take longer.

Creating experimental units in livestock research. The experimental unit is the physical entity that can be assigned, at random, to a treatment. In livestock studies, it is typically an individual animal. However, any two experimental units must be capable of receiving different treatments. Thus, in a feed study where cows in a pen are given a treatment in the diet, the pen of animals rather than the individual animal is the experimental unit, because the cows in the same pen eat from the same source and cannot be given different diets. If, however, the treatment can be given to individual animals in the pen, such as a medication, then individual animals in the same pen can be used as experimental units.

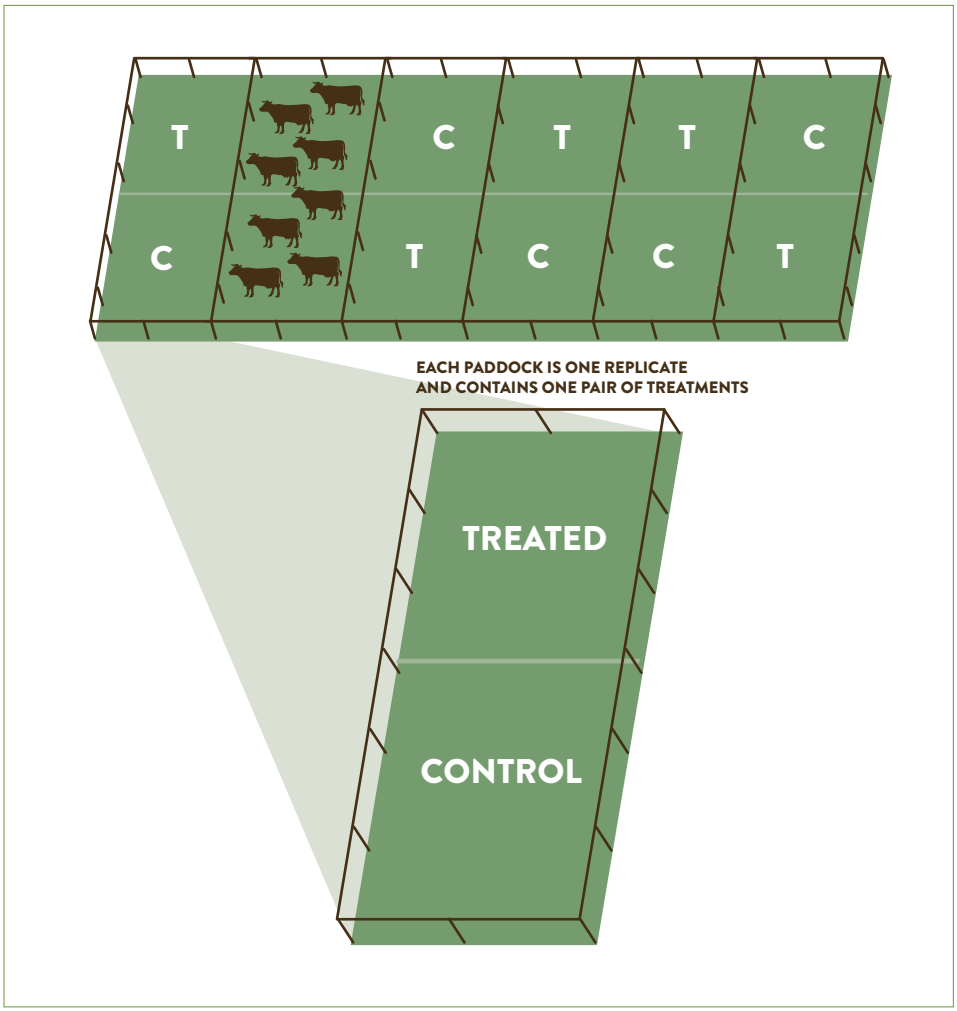
Creating experimental units in pasture research. If you are conducting the experiment in established paddocks that have set perimeter fences, creating experimental units is relatively easy. You can divide each paddock roughly in half and consider each half to be one experimental unit. Each paddock is one replicate and will contain one pair of treatments (treated and control). You will need six paddocks to complete this experimental design (see Figure 10). If you are conducting the experiment in an area that is strip grazed, setting up the experimental units will require a bit more work. You will be applying the treatments

in long narrow strips. Each strip will be one experimental unit. Two adjacent strips will be paired. It is helpful, if you are applying the treatments with a tractor, to make plots that run the length of the field and are 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. Decide what width you would like each strip to be; use flags or markers to mark the chosen interval within the field.

Determining experimental design. With livestock studies, animal-to-animal comparisons are used when the treatment being studied can be applied to individual animals (e.g., a mastitis treatment in which the experimental unit is the individual animal). For purposes of experimental design, you might establish a treatment A group, a treatment B group and a control group, with each animal a replication. In studies that use pens or other enclosures as the experimental unit, such as feed studies, you would use several pens of animals to achieve replication. Limiting factors in your ability to do a pen-to-pen study may include your housing or the size of your herd.

The paired comparison design is well-suited to pasture research. By replicating the treatment within every pasture, many factors, such as grazing use, are kept constant. The design is fairly simple to understand and implement; each data pair yields one difference. These differences can be analyzed using the t-test protocol outlined in the statistical analysis section of this

FIGURE 10. Sample Paired Comparison Design for Farm with Permanent Paddocks

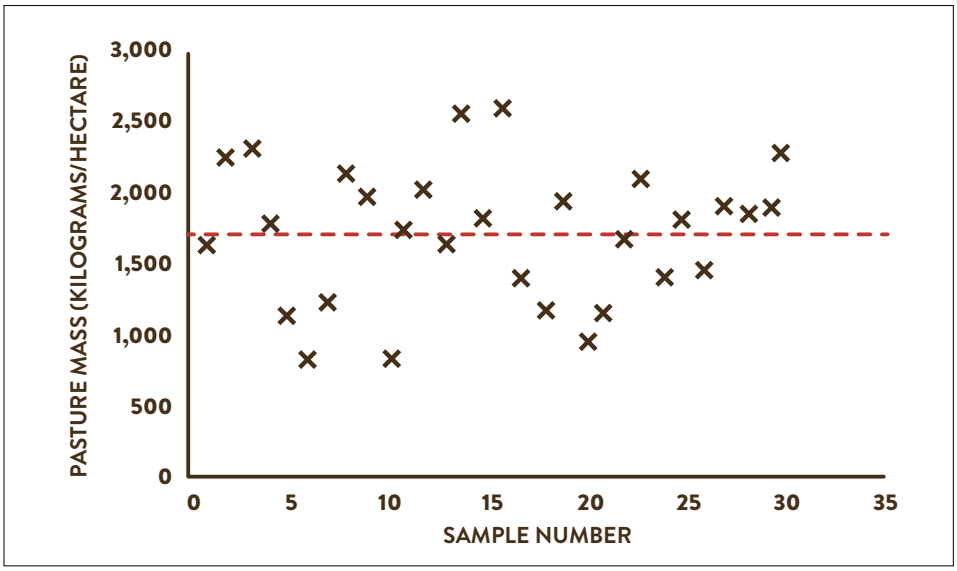


In this example, each paddock is a replicate. Paddocks have been divided in half with each half receiving, at random, the treatment or the control. Flags or fence posts are useful to mark where one treatment ends and the next one begins. A detailed map is the best way to keep track of how the treatment and control were assigned. Adapted from Hilshey (2013).

TABLE 6. Common Variables in Livestock/Pasture Research

ANIMAL MEASUREMENTS	SOIL PROPERTIES	FORAGE VARIABLES
Daily milk production	Soil organic matter	Forage mass
Weight change (daily, weekly, monthly or before and after treatment, with scale or physical body measurements)	Soil nutrient content	Percent desirable species
Body condition scoring (use agreed-upon standards for cattle and small ruminants)	Soil pH and cation exchange capacity	Plant cover
Animal health or disease ratings (e.g., mastitis)	Soil compaction	Plant diversity
Percent conception	Soil moisture	Forage quality
Calving, kidding, lambing rate	Earthworms and other biological measurements	Plant Brix content
Survival of young at one day, one week, one month, etc.		Visual assessments
Calf weight		Protein and carbohydrate content
Meat quality (e.g., fat content)		
Egg production		

FIGURE 11. Pasture Forage Variability and the Importance of Taking Many Subsamples



In pasture research, you will often need to take 20 to 30 subsamples from an experimental unit to find a true average. This high rate of subsampling accounts for the wide variability that can occur in soil and forage conditions within even a small paddock. Adapted from Hilshey (2013).

publication. In pasture research, the paired comparison is usually characterized by having long strips of treated and untreated (control) land side by side in the field, replicated at least six times. Each pair of strips should be located in an area that is fairly uniform.

Choosing variables to measure. The kinds of data you collect depend on your research objectives. Some of the common measurements you might collect in livestock and pasture-based research are presented in Table 6.

Specialized equipment and lab analyses are required for some of these measurements, so check with your Extension agent to see where those might be obtained. Be sure that what you are measuring will answer your research question. It is easy to overextend yourself by measuring more variables than you have time or money for. We recommend focusing on two to four variables.

In pasture research, when measuring variables such as soil nutrient content and forage mass, it may be necessary to take many subsamples in order to increase precision. Pastures are "fertilized" and "harvested" by animals; the forage within them is a dynamic, diverse, living community of plants. As a result, the characteristics of the pasture can vary greatly within a small area. To overcome the variability, many samples must be taken in order to accurately estimate what the experimental unit is really like. Usually 30 samples are recommended for an experimental unit a half acre or greater in size. For smaller experimental units, 15 to 20 samples are adequate (see Figure 11). For samples that are shipped to laboratories for analysis, thoroughly mix together at least 20 (or more) samples collected from one experimental unit. Then select a portion of aggregated sample to send out for analysis. Always strive for a good, representative sample.

Analyzing the data. Once you have your data, the statistical analyses are the same as described previously in the section Basic Statistical Analysis for On-Farm Research. If you do get a significant difference between your treatment and your untreated control, what does it really mean? If your treatment yielded 20 percent more pasture mass than the untreated control, will that really result in 20 percent more available pasture for your animals? Using your results, you may now decide to expand your test to a larger pasture area. One approach would be to treat an area that normally (based on past records) gives you about four days' worth of grazing. Will the treatment now give you five days of grazing in that area?

Tips for On-Farm Livestock Research

- Have good, reliable scales for livestock, feed, forage, etc. Check them often with something of known weight.
- Use several pens or paddocks of the same size for side-by-side, pen-to-pen comparisons.
- Use two or more feed storage bins for feeding trials, if you are using different diets.
- Allot or assign animals to the treatments carefully. The pens need to be as much alike as possible, with equal numbers of heifers and steers grouped together in one pen, or both larger and smaller animals included in each pen.
- Weigh animals. Cattle, especially, can have varying amounts of feed and water, or fill, in their digestive tracts. The rumen in a mature cow's stomach can hold 42 gallons, or 350 pounds. Weigh the cattle in the morning before they are fed, under the same conditions. If the cattle are on pasture, they should be penned in a dry lot the night before weighing.
- Animals unexpectedly die during experiments. Record the date, cause of death and weight of the dead animal as soon as it is discovered. These records are helpful in accounting for the feed and gain of the dead animal.
- Use a team approach. Feed suppliers, veterinarians, Extension or university staff, and electric fence suppliers make great team members. Link with other livestock producers with similar interests.
- Think about what you are measuring. Animal growth or weight gain, feed intake, days on feed and milk production are common measurable livestock outputs.
- Write it down! Keeping notes about your observations may be as important as actual data.
- Start small and keep it simple. Do not design elaborate comparisons, particularly at first.
- Use available technology. All-terrain vehicles, cellphones, ear tags, electric fencing, freeze branding and plastic water pipe make many studies possible.

PROFILE Harry Cope, Cope Grass Farms

Missouri farmer Harry Cope uses trays to estimate the percentage of cover crop seeds that reached the ground when broadcast into standing corn (left). He experimented with skip-row corn planting to see if it would improve germination and establishment of a cover crop mix of peas, kale, annual ryegrass, oats, Daikon radish and cereal rye (right). His on-farm research looked at planting techniques to improve fall grazing for sheep. *Photos by Rich Hoormann, University of Missouri Extension*

Skip-Row Corn Planting Techniques with Cover Crops for Sustainable Grazing

Harry Cope is one of a growing number of farmers nationwide using cover crops to improve soil quality and enhance their production system. He farms 1,300 acres near Truxton, Mo., where he raises cattle, sheep and goats. Cope uses management intensive grazing (MIG) on all his pasture land, and has about 115 acres in crop production. As part of his pasture rotation, livestock graze corn in the fall. This has worked well, but Cope wondered if the amount of forage available to livestock could be increased by planting a cover crop into the standing corn in July or August. Very little direct sunlight can reach the soil surface in a standing corn crop at that time of the season, so that presented Cope with a challenge: how to maintain the period that livestock have to graze the corn forage, and at the same time give a cover crop the growing conditions it needs to become established and grow well. An earlier-emerging and more robust cover crop could result in greater forage mass, higher-quality forage and lower grazing costs for sheep and cattle.

Research Questions/Objectives

Cope's idea was to skip some rows when planting corn so that he could plant the cover crop mix directly into the standing corn crop. With skip-row corn planting, enough light would reach the soil surface to promote cover crop germination and establishment. Skip-rows would also make it easier to set up the portable electric fencing required for his MIG systems. With that general idea in mind, Cope arrived at the following research question: What is the most productive combination of corn population, skip-row planting techniques and cover crops seeded into standing corn for increasing dry matter yield for fall grazing by sheep? "Productive" in this context meant maximizing both corn dry matter (vegetation) and cover crop growth as part of the total feed available to the livestock.

Experimental Design

In order to answer his research question, Cope conducted a three-year study. Using a randomized complete block design, he laid out five replications (blocks) in a 15-acre field. Each replication consisted of four treatments, and each of the 20 plots was 0.75 acres. Treatments were randomized within each block and the experimental design remained the same during the three years of the project. The four treatments for planting corn were as follows:

- Solid stand 26: six rows of a six-row planter with 26,000 population
- Solid stand 20: six rows of six-row planter with 20,000 population
- Skip-row 26: rows one, three, four and six of six-row planter with 26,000 population, rows two and five bare
- Skip-row 32: rows one, three, four and six of six-row planter with 32,000 population, rows two and five bare

In each year of the study, the corn was planted at the same time for all plots and managed consistently throughout the growing season. A mixture of different cover crops (peas, kale, annual ryegrass, oats, Daikon radish and cereal rye) was broadcast into the

Harry Cope, Cope Grass Farms, *continued*

Missouri farmer Harry Cope's experimental design included treatments that left two out of every six rows bare, in an effort to see if skip-row corn planting could improve germination and establishment of a cover crop broadcast into standing corn. *Photo by Rich Hoormann, University of Missouri Extension*

standing corn crop as it attained its final vegetative growth stage (about 10 leaves to tasseling). The corn and cover crops were harvested in the fall, and Cope collected data on corn grain yield, corn biomass production and cover crop biomass production.

A portion of the corn and cover crop plots was harvested in September. Cope conducted a separate grazing study on the non-harvest area of plots to see how lambs would do grazing corn. (He already knew that beef cattle and ewes could graze corn successfully.) Three groups of lambs were tagged, weighed and placed in three grazing treatments: 1) corn, cover crops and hay, 2) pasture, free access to corn and cover crops, and 3) pasture only, as a control. The grazing trial ran 47 days, and at the end, lambs were weighed again to determine weight gain.

Statistical Analysis and Findings

Overall, Cope's project provided him with information that helped him refine his ideas about using cover crops in standing corn for early fall grazing.

Data from the corn-cover crop plots was analyzed using ANOVA. The results showed that cover crops can be planted into standing corn during July and early August, but it was not clear which corn planting density was optimum. There were differences among the treatments, but according to the statistics, those differences were not significant due to substantial rainfall differences in July-August-September time frame during the three-year time frame. By keeping accurate field notes over each growing season, Cope noted that the hybrid kale, annual ryegrass, oats, field peas and crimson clover all did well under this planting scenario; the radish and cereal rye had difficulty becoming established. Based on his experience with this project, Cope concluded that he could not really count on cover crops to increase the dry matter in standing corn for early fall grazing. With the type of soil on his farm (primarily a silt loam), cover crops for grazing are only successful if there is enough rain at the right frequency to get the cover crop up and growing. With that added uncertainty, more research is needed to determine if this strategy is worth pursuing.

Statistical analysis for the grazing portion of the study used ANOVA in the first year and an independent t-test in the second year to determine any significance differences in weight gain between the three groups of lambs. The data showed that lambs are not able to figure out how to make use of corn to meet their nutritional needs. A few individual animals gained weight with the corn forage treatments, but as a group, the lambs did not show significant gains with corn. Based on these results, Cope concluded that mature dry corn does not fit the grazing need in October-December for feeder lambs, and the dry matter per acre of seeding cover crops into standing corn was not great enough to compensate for the lambs not knowing how to feed on ear corn or dry leaves. Ewes or beef cattle would be better suited to graze standing corn with cover crops in this time period.

Project Team

Cope had assistance from Rich Hoormann, Charles Ellis and Wayne Shannon, all with University of Missouri Extension, on this project.

LEARN MORE

To learn more about this project, including an analysis of the data, visit www.sare.org/project-reports and search for project FNC10-817.

Visit www.sare.org/harry-cope for a story about Cope's project, including video of a presentation he gave in 2012.

Other Types of Research Farmers Can Do

Changing production practices or modifying your farm or ranch system in some way can be risky, so be sure that you have used correct experimental design and statistical methods to ensure that you have clear, accurate information on which to base your decisions. However, you might ask: "What if I am not quite ready to work on a project of this type? Are there other kinds of research I can do on my farm that will provide useful information?" The answer is yes. Although on-farm research has been defined fairly narrowly in this publication, there are other avenues for experimenting with new varieties or production practices to find answers to your questions.

On-Farm Demonstrations and Variety Trials

The beginning of this publication distinguished between on-farm research and on-farm demonstrations or variety trials. Whereas on-farm research helps identify and validate answers to specific research questions, the goal of on-farm demonstrations is to show other farmers, and help you gain experience with, some new technology, variety or production practice. Since on-farm demonstrations do not contain a research component, yield responses or other data need not be measured or statistically analyzed. Instead, you carefully observe and take detailed notes about what is happening in the field over the course of the growing season. You are mostly looking for patterns, so your observations and notes could include environmental factors (e.g., rainfall, temperature, other weather events), soil conditions, field operations, pest problems and information about your crop such as germination rates, health of the plants and overall crop growth. Yield quantity and quality can be a part of that observation, but you should not rely on that limited amount of information to make decisions about which practices or varieties are ultimately better. You would need a well-designed, replicated experiment to confirm any observed patterns of differences. Variety plots are a great example of how on-farm demonstrations can be a valuable tool for farmers in generating useful information. Read the profile of farmer Theresa Podoll to learn more.

Qualitative Research

Qualitative research methods are used in many different fields, especially in the social sciences and education. With qualitative research, whatever is being studied (e.g., human behavior, animal behavior, marketing strategies, community dynamics, program effectiveness) is explored *in context*. Researchers look closely at the factors that influence their research population and try to correlate findings with key characteristics of that population. The researcher usually does not introduce treatments or manipulate variables. Rather, they gather data through interviews, detailed case studies or certain kinds of surveys. They also use existing data sets extensively for background research and to corroborate findings and conclusions. Along with conceptualizing the research and carrying out the data collecting, researchers involved in qualitative research also word questionnaires and surveys, and conduct one-on-one interviews with project participants. In addition, qualitative research offers flexibility, as researchers can adjust the scope and techniques for collecting data as patterns emerge. Table 7

TABLE 7. Differences Between Quantitative and Qualitative Research

CHARACTERISTIC	QUANTITATIVE RESEARCH	QUALITATIVE RESEARCH
General goals of investigation	Predicting, comparing, confirming, hypothesis testing, how much, how many	Understanding, explaining, hypothesis generating, why and how
Design of studies	Established protocols, structured	Flexible, evolving, emergent
Sample	Large, random, representative	Small, selective, purposeful, non-random
Data collection	Researcher uses instruments to measure, weigh, calculate	Researcher interacts directly with study participants through interviews and focus groups
Mode of analysis	Deductive using statistical methods	Inductive through dialog and interaction to discover patterns
Findings	Precise, narrow, reductionist, generalizable	Comprehensive, holistic, expansive, not generalizable

Adapted from *Case Study Research in Education: A Qualitative Approach*. S.B. Merriam. 1991. Jossey-Bass, San Francisco.

On-farm demonstrations, like this one dedicated to cover crops that Steve Groff held on his Pennsylvania farm, help producers, researchers and educators share insights about new production practices, technologies or crop varieties. *Photo by Mandy Rodrigues, SARE*

summarizes some of the key differences between qualitative and quantitative research methods described in earlier sections of this publication.

Market Research

To run a successful business, it is critical that you understand your market, particularly if you are engaged in direct marketing or value-added production. You need to know about market trends, your customers (their needs, desires and preferences), your competitors and prices. Thorough research is necessary to gain the confidence that people will buy your product. And if they will buy it, will they pay an adequate price for you to make a profit? Market research can help you gather this information.

For example, see the profile of Good Natured Family Farms, a Kansas City-area cooperative whose members conducted marketing research to learn more about consumer preferences regarding meats and other products they had to offer.

Market research involves qualitative methods (e.g., interviews, focus groups), quantitative methods (e.g., surveys that provide numerical data) or a combination of the two. However, with limited time and resources, you might want to consider whether primary research is required, or if secondary research will suffice. Primary research involves collecting new data through market surveys, personal interviews or focus groups. You might do this work yourself, or hire someone to conduct the study on your behalf. Secondary research involves gathering pre-existing information from published sources and databases.

If you decide to conduct your own marketing research, consider the following steps:

- Take advantage of what others have learned through market analysis. Contact other producers who specialize in your product, publicly held companies that post earnings statements and government agencies. Search libraries for books, reports and journals. Contact agricultural Extension offices and search the Internet.
- Be precise about the question you want to answer. The narrower your question (e.g., "What cut of beef would sell best at a farmers' market?"), the more efficiently your research can answer it.
- Quantitative research, such as surveys that ask people to rate the importance of various product characteristics to them or the likelihood they would buy your product and the price they would pay for it, will offer information that you can extrapolate to a larger population as you attempt to determine the size of your market and your profit potential.
- Qualitative research, such as focus groups and semi-structured interviews, can help you understand consumer preferences in more depth and figure out the right questions to ask in a structured survey. In-depth discussions can also help you determine the underlying reasons behind consumer choices, which can help you devise marketing and branding strategies for your product.

LEARN MORE

To learn more about market research, check out the Resources section. The Agricultural Marketing Research Center (AgMRC) is a great place to start.

PROFILE **Theresa Podoll, Prairie Road Organic Seed**

Screening Open-Pollinated Vegetable Varieties Bred and Released in North Dakota for Suitability to Organic Production Systems and Local Markets

Organic and direct-market farmers are always looking for the best crop varieties—ones that produce well in their area, are able to withstand pest and disease problems, and give them an edge in the marketplace. Many farmers are also keen on finding open-pollinated varieties, which remain true to type when you save their seed. To fill this need, growers are increasingly looking back in history for older varieties that have those special qualities and characteristics. But, as a farmer, where do you start your search? Seed catalogs can help, but most regionally significant varieties with specific adaptation traits dropped out of the seed trade long ago.

Theresa Podoll of Prairie Road Organic Seed sees this as a tragic and significant loss to gardeners and market growers. She, her husband and extended family have been producing certified organic seed on their 480-acre farm in south-central North Dakota since 1997 and were acutely aware of this need through their business contacts and the various farmer networks they were part of in the region. Knowing that it takes a great deal of time and effort to test and evaluate crop varieties over the course of a growing season, Podoll and two other farmers joined with the Northern Plains Sustainable Agriculture Society and North Dakota State University in 2009 to address this important need.

Research Questions/Objectives

Podoll's goal for the two-year project was to increase the number of vegetable crop varieties well suited to organic production systems and local markets in North Dakota. Under this goal, she had three objectives:

- Screen a minimum of 60 vegetable varieties for agronomic and quality traits of interest to North Dakota market growers (10 per farm per year).
- Identify at least 12 North Dakota bred, open-pollinated varieties of vegetable crops with agronomic and quality traits of interest.
- Facilitate seed increases of at least nine varieties based on variety trial results and farmers' market taste tests.

Experimental Design

To identify varieties to include in the screening trials, Podoll gathered information through a survey of the North Dakota Farmers Market and Growers Association, and also consulted archives from North Dakota State University (1926-1991) and varieties bred and selected for the Oscar H. Will and Co. seed catalog (1896-1969). Varieties of interest were researched and seed procured through the Germplasm Resource Information Network system, heirloom seed catalogs and seed-saving organizations, such as Seed Saver's Exchange, Abundant Life Seed Foundation and Seeds of Diversity Canada. These seeds were included in variety screening trials held in 2010 and 2011.

Each farmer participant conducted vegetable variety screenings of at least 20 varieties: planting, maintaining, monitoring and documenting performance and results using photos and variety evaluation forms. In each of these non-replicated demonstrations, a combination of quantitative (e.g., height, yield or fruit size) and qualitative data (e.g., seedling vigor, color, flavor, disease and pest resistance, and uniformity) was collected.

Traits of interest for each of the crops selected were discussed by the group. Variety trial evaluation sheets were provided by the Organic Seed Alliance. Each of the farmers screened different varieties to gain experience with as many varieties as possible in the two-year project. The farmers gauged their interest in continued production, while noting beneficial and deleterious traits, and any needed improvements to make the crop and variety work for their farm and production system.

Analysis and Results

Seed was saved from 14 varieties; five varieties have undergone continued evaluation, and nine varieties continue to be grown out and selected for variety improvement and seed production. These varieties include Alaska and Homesteader peas, Pinky popcorn, Mantador broccoli, Hidasta Red and Arikara Yellow beans, Sheyenne and Manitoba tomatoes, and Granite State cantaloupes.

"Once you find varieties of interest, implementing sound seed production and maintaining trueness to type may be a challenge," Podoll said. "Seed saving is an art requiring both knowledge and skills, and is so needed to maintain seed diversity."

Project Team

Participating Growers
Theresa Podoll, Prairie Road Organic Seed
Steve Zwinger, Prairie Seeds
Marvin Baker, North Star Farms

Technical and Outreach Assistance
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Sue Balcom, North Dakota Department of Agriculture
Holly Mawby, Dakota College at Bottineau
Annie Carlson, FARRMS
Stacy Baldus, Dakota College at Bottineau

LEARN MORE

To learn more about this project, visit www.sare.org/project-reports and search for project FNC09-754.

Visit the Prairie Road Organic Seed website at www.prairieroadorganic.co.

PROFILE Good Natured Family Farms

Getting to the Meat of the Matter: In-Store Surveying Informs Beef Producers

In 1997, before members of a Kansas City, Mo., cooperative that wanted to market "natural" meat and other farm products began soliciting area grocery stores, they conducted a comprehensive, SARE-funded marketing research effort.

Working with scientists at Kansas State University, Good Natured Family Farms (GNFF) created surveys to assess preferred beef cuts both from grocery meat managers and customers, who could sample and record their impressions at an in-store computer kiosk. In addition to the survey, the alliance hosted in-store product demonstrations with free drawings to incentivize participants. By collecting this data, GNFF was able to determine what cattle breeds and feeding procedures provided the most profit potential.

Consumers indicated they wanted to know how their meat was raised and said they read labels to ascertain the presence of artificial additives and preservatives. Perhaps most important, those surveyed said "taste and tenderness" outweighed price as purchasing factors.

It came as no surprise that the retail meat managers surveyed preferred cuts of loin to round, rib, chuck and ground beef. The taste test findings encouraged co-op members, most of them third- and fourth-generation ranchers, to supply cuts such as strips, ribeye, top round and top sirloin, and to add value to lower cuts in hot dogs and beef jerky.

Now, the more than 100 members of the Good Natured Family Farms (GNFF) alliance know what their customers like, such as labels indicating meat is "free of additives," grown locally and produced in accordance with Good Agricultural Practice (GAP) standards—and they market accordingly. By working together to conduct marketing research, GNFF members enhanced their marketing skills and learned how to achieve a common goal: profitability through understanding of their market and customers.

"Market research allows you to identify your consumers and the products that work and don't work," said Diana Endicott, an organic beef and chicken rancher who has been instrumental to the co-op's growth. "It helps you find out who wants your product and how much they're willing to pay," and it never hurts to make a supporter out of the person customers see behind the counter. "When the consumer asks what it tastes like, they can answer them," Endicott pointed out.

LEARN MORE

To learn more about this project, visit www.sare.org/project-reports and search for project FNC97-171.

Visit the Good Natured Family Farms website at www.goodnaturedfamilyfarms.com.

Resources

On-Farm Research

On-Farm Trials for Farmers Using the Randomized Complete Block Design. Phil Rzewnicki, University of Nebraska – Lincoln. 1992.

On-Farm Research Guide. Jane Sooby. Organic Farming Research Foundation. 2001.

On Farm Research Guide. Sharon Rempel. Published by The Garden Institute of Alberta, Edmonton, Alberta, Canada. 2002.

A Field Guide for On-Farm Research Experiments. Keith Baldwin, North Carolina State University Cooperative Extension. www.sare.org/on-farm-research-field-guide. 2004.

On-Farm Testing: A Grower's Guide. Baird Miller, Ed Adams, Paul Peterson, Russ Karow. Washington State University Extension. 1992.

A Practical Guide to On-Farm Research. R.L. Nielsen, Agronomy Dept., Purdue University. 2010.

A Practical Guide to On-Farm Pasture Research. Bridgett Hilshey, Sidney Bosworth, Rachel Gilker. www.sare.org/practical-guide-to-on-farm-pasture-research. 2013.

The Paired Comparison: A Good Design for Farmer-Managed Trials. Rick Exner and Dick Thompson, Practical Farmers of Iowa. This seven-page paper features real-life examples and worksheets. 1998.

On-Farm Testing – A Scientific Approach to Grower Evaluation of New Technologies. Pacific Northwest Conservation Tillage Handbook Series No. 9; Chapter 10, by Roger Veseth et al. 1999.

A Field Guide to Experimental Designs. Jerry Tangren, Washington State University. 2002.

Guide to On-Farm Replicated Strip Trials. Peter Kyveryga, Tristan Mueller, Nathan Paul, Allie Arp, Patrick Reeg. The Iowa Soybean Association's On-Farm Network.

Successful Research Design and Methodology for Grant Proposals. Andrew Ristvey and Nevin Dawson, University of Maryland. This one-hour webinar explains practical research methodology and design, in order to help producers develop projects and write grant proposals. www.sare.org/successful-research-design-and-methodology-for-grant-proposals. 2014.

Grower's Guide to On-Farm Research. Nebraska On-Farm Research Network, University of Nebraska-Lincoln Extension. 2013.

Qualitative Research/Market Research

Building a Sustainable Business: A Guide to Developing a Business Plan for Farms and Rural Businesses. See "Planning Task 4: Strategic Planning and Evaluation—What Routes Can You Take to Get Where You Want to Go?" Gigi DiGiacomo, Robert King, Dale Nordquist. Sustainable Agriculture Research and Education. 2003. Download or order at www.sare.org/business.

Case Study Research in Education: A Qualitative Approach. S.B. Merriam. 1991. Jossey-Bass, San Francisco.

Market Research (Agricultural Marketing Resource Center). www.agmrc.org/business-development/starting-a-business/marketbusiness-assessment/market-research.

Conducting Market Research and Marketing Research Tools. Mary Holz-Clause. Iowa State University Extension's Ag Decision Maker. 2010. Visit www.extension.iastate.edu/agdm/vdmarketing.html and see publications C5-30 and C5-22.

Systems Research

Systems Research for Agriculture. 2016. Drinkwater, L. E., D. Friedman and L. Buck. Sustainable Agriculture Research and Education. www.sare.org/Systems-Research-for-Agriculture.

Perspectives on Systems Research. Gwen Roland. Southern SARE. 2010. www.southernsare.org/perspectives-on-systems-research.

Resources, *continued*

Videos

Conducting On-Farm Research video series. University of Nebraska-Lincoln CropWatch. Visit http://go.unl.edu/on-farm-videos. 2014.

Statistical Analysis Software

AGSTATS02. An easy-to-use, Windows-based software for statistical analysis of simple on-farm field experiments. Washington State University. http://pnwsteep.wsu.edu/agstatsweb.

Farmer/Researcher Networks

Alternative Energy Resources Organization (AERO). Grassroots membership organization helps organize groups of farmers and ranchers interested in exploring sustainable techniques. (406) 443-7272; or www.aeromt.org.

North American Farming Systems Association On-Farm Research Listserv. To share information and questions about on-farm research, contact sejohnson@smallfarm.org.

Practical Farmers of Iowa. A 600-member organization founded in 1985, PFI is dedicated to sharing information that supports farmers, their environment and their communities. Contact (515) 232-5661 or visit www.practicalfarmers.org for more information.

Rural Advancement Foundation International-USA (RAFI-USA). Based in North Carolina, RAFI-USA supports peanut and tobacco farmer networks developing more sustainable production methods. Contact Scott Marlow, (919) 542-1396; smarlow@rafiusa.org or visit www.rafiusa.org.

Nebraska On-Farm Research Network. Works directly with Nebraska farmers to address their production and profitability questions using on-farm research. Contact Keith Glewen at KGlewen1@unl.edu or http://cropwatch.unl.edu/farmresearch.

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