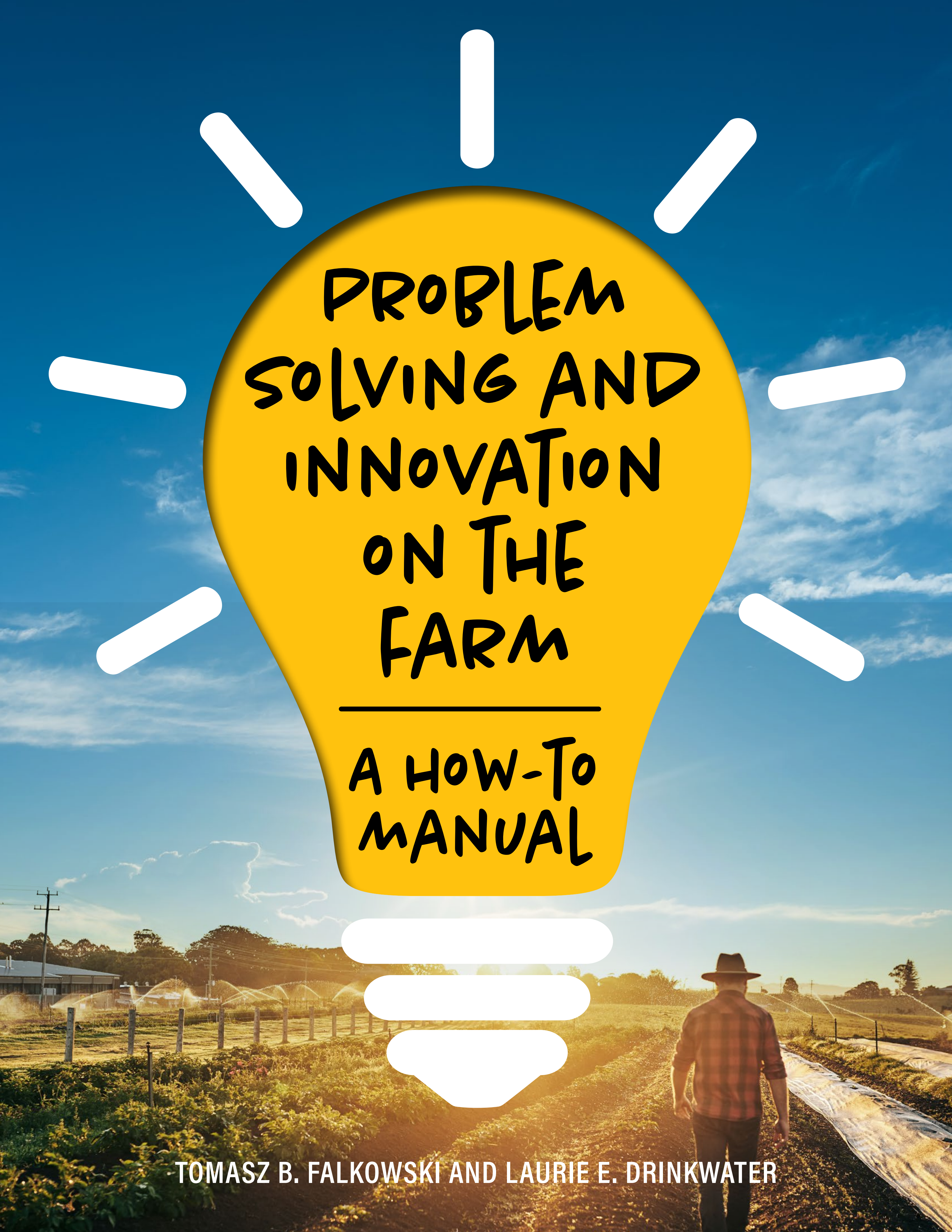

Problem Solving and Innovation on the Farm

A How-To Manual

TOMASZ B. FALKOWSKI AND LAURIE E. DRINKWATER

Contents

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1 Introduction

Ask any farmer, and they'll tell you that their job is never boring. Farmers deal with new challenges that arise on a near-constant basis, be it unpredictable weather, new pests, volatile prices, or changing customer preferences. If anything, the speed and magnitude of these changes are likely to increase in the coming years as a result of environmental shifts, accelerating technological development, and an increasingly interconnected economy. As a result, it's advantageous—and arguably essential—for farmers to develop problem-solving skills.

Although the ability to respond to change is a key feature of adaptive farm management, problem solving and the ability to develop innovations are often seen as innate skills rather than something that can be learned. Some farmers consider the development of innovative solutions to be extensionists' and researchers' job. By contrast, farmer-innovators are those farmers who have integrated problem solving and experimentation into their normal farming operations. The solutions they find are appropriate for their farms and are generally more successful than generalized, cookie-cutter fixes. In some cases, they even discover a new solution that is broadly applicable across farms.

In this manual, we present a step-by-step process for on-farm problem solving and experimentation and provide real-world examples of this approach in action. In learning from these farmer-innovators' collective experience, we believe that you can also become an innovative farmer ready to tackle any of the challenges that inevitably lie in your future.

How this manual was developed

Our conversations over the years with experienced farmer-innovators inspired us to embark on this project. We learned that each of these farmers had developed inventive approaches to combine experimentation with their normal farming activities. These systems of inquiry had some common patterns across farms while also

being fine-tuned to be compatible with each farmer's personality and management style. We systematically documented these farmers' techniques and processes to produce this manual in the hope that this information would be useful to other farmers and extension educators.

The Northeast Sustainable Agriculture Research and Education program funded our proposal, and we held the initial focus group workshop on March 1-2, 2017. The focus group consisted of nine organic farmers who both we and other farmers identified as innovators. We included farmers who maintained a range of production systems (e.g., grain, vegetables, livestock). The product of the workshop was the seven-step system for on-farm problem solving and innovation illustrated on page 9.

We also conducted individual interviews with the farmers who participated in the initial workshop as well as farmers who were recommended to us. These interviews clarified the results of the workshop and provided specific examples of on-farm problem solving and innovation. We incorporated feedback from farmers, extension educators, and researchers who reviewed the completed manual. We hope this manual will not only offer guidance for aspiring farmer-innovators, but will also help explain farmer problem solving and innovation to the broader community of agricultural professionals, including scientists and extension educators.

Content and organization of the manual

Many guides lay out basic on-farm research approaches (see the references provided at the end of Chapter 5). These resources emphasize different aspects of the process, but they all try to help farmers apply the scientific method to conduct on-farm trials. Taken together, these manuals provide an excellent guide to applying simple research approaches that follow the scientific method.

This is not our goal with this manual. Instead, we are presenting informal, farmer-developed methods used by experienced and innovative farmers that are compatible with day-to-day farming activities. Most of these farmers are aware of the basic elements of the scientific method but developed their own approaches for studying their farms that don't completely match the requirements of formal research. Rigorous experimental designs have led to countless discoveries, but we are increasingly recognizing the importance of other, complementary approaches to producing knowledge, including those developed by people who aren't necessarily trained in the scientific method.

We start by introducing the Problem Solving and Innovation Framework in Chapters 1 and 2, along with some background about the role of farmers in agricultural innovation and adaptive management approaches. Subsequent chapters cover the details of the seven-step process, developed by the farmer focus group. Chapter 3 focuses on developing life and farm goals that are a necessary foundation of effective experimentation and problem solving. This chapter is most relevant to new farmers or those who are contemplating starting a farm. Chapter 4 deals with identifying and prioritizing problems and opportunities for improving a farming system. We focus on aspects of these tasks that are particularly relevant to problem solving and innovation rather than discussing general farm management at length. Chapter 5 then builds upon this groundwork to describe how to design, execute, and evaluate on-farm experiments.

“We hope this manual will not only offer guidance for aspiring farmer-innovators, but will also help explain farmer problem solving and innovation to the broader community of agricultural professionals, including scientists and extension educators.”

The final two chapters of the manual include material that complements and expands on the Problem Solving and Innovation Framework. We provide example problems with suitable experimental designs and diagrams in Chapter 6. Chapter 7 contains 11 case studies documenting illustrative real-world examples of farmers problem solving and innovating.

Lastly, at the end of each chapter, we have provided a number of useful resources associated with the content of the problem-solving steps. In addition, several appendices at the end of the manual provide additional resources, including a list of farmer networks and agricultural organizations that support farmer problem solving and adaptive management, worksheets, funding sources for on-farm research grants, and information on personal weather stations. Throughout the manual, hyperlinks are indicated with blue text; those that connect to internal sections within this document are underlined.

2 How do expert farmers solve problems on their farms?

Overview of the Problem Solving and Innovation Framework presented in this manual

The Framework that was developed by the farmer focus group (Table 2-1) is divided into two parts (Figure 2-1). Part I (Steps A and B) includes steps that focus on establishing a farm vision and understanding your whole farming system. The farmer panel agreed that having a solid vision and farm plan is the foundation of effective problem solving and innovation. Once established, these steps can be revised periodically (i.e., every 5–10 years) or when there are events that require you to reconsider your vision or farm plan (i.e., having children, moving from rented to owned land). Part II (Steps C–G) emphasizes observing and evaluating your farming operation in order to spot areas in need of improvement and takes you through the process of experimentation including designing, implementing, and evaluating on-farm trials in conjunction with normal farming activities. This cycle is typically repeated annually.

While we have organized the steps and tasks of the Framework in a sequence that reflects the consensus of the farmer panel, in practice, farmers don't solve problems in a linear fashion. You may find that your preferred sequence differs from the order outlined in the Framework (Figure 2-2). You might also find that in some cases, you don't need to carry out all steps or tasks. This is particularly true in the case of urgent problems that need a speedy solution; it might be prudent to shorten certain steps or skip them entirely.

TABLE 2-1: The Problem Solving and Innovation Framework is composed of steps and tasks that farmer-innovators agreed were important for the problem-solving process. Tasks flow from left to right, but the precise order of actually implementing them is flexible.

Parts		Steps	Tasks		
Part I	A	Identify the farm vision	**A-1:** Network with farmers	**A-2:** Identify quality of life requirements	**A-3:** Identify personal/farm values and goals
			A-4: Articulate farm vision	**A-5:** Identify target market	**A-6:** Write business plan
	B	Define the farm system	**B-1:** Map the farm	**B-2:** Identify resource inventory	**B-3:** Develop whole farm plan
			B-4: Determine means of production	**B-5:** Determine farm interactions	
Part II	C	Observe/gather information on the farm system	**C-1:** Walk the farm	**C-2:** Record observations and events	**C-3:** Observe patterns
			C-4: Perform routine testing	**C-5:** Collect outside observations	**C-6:** Taste your own food
			C-7: Invite feedback from farm staff	**C-8:** Invite feedback from customers	**C-9:** Assess equipment
	D	Evaluate the farm system	**D-1:** Review annual farm schedule/calendar	**D-2:** Analyze financials	**D-3:** Analyze records
			D-4: Establish benchmarks	**D-5:** Review successes and failures	**D-6:** Review means of production
			D-7: Identify important trends/changes	**D-8:** Consult experts	**D-9:** Prioritize problems and opportunities
	E	Design actions	**E-1:** Investigate subject	**E-2:** Research solutions/ options	**E-3:** Assess risks and rewards
			E-4: Choose best course of action	**E-5:** Design trial/course of action	**E-6:** Identify success criteria
	F	Implement your plan	**F-1:** Collect resources	**F-2:** Allocate necessary time	**F-3:** Assign roles and duties
			F-4: Execute plan	**F-5:** Collect data	**F-6:** Monitor results
			F-7: Fine tune actions	**F-8:** Review success criteria	
	G	Evaluate Outcomes	**G-1:** Observe end result	**G-2:** Analyze data	**G-3:** Reassess risks and rewards
			G-4: Invite feedback	**G-5:** Determine next steps	**G-6:** Share results

FIGURE 2-1: Relationship between Innovation Framework sections. The steps in Part I inform those in Part II (large arrow), and you can use the information you learn from Part II to occasionally revisit your farm vision and system in Part I (small arrow).

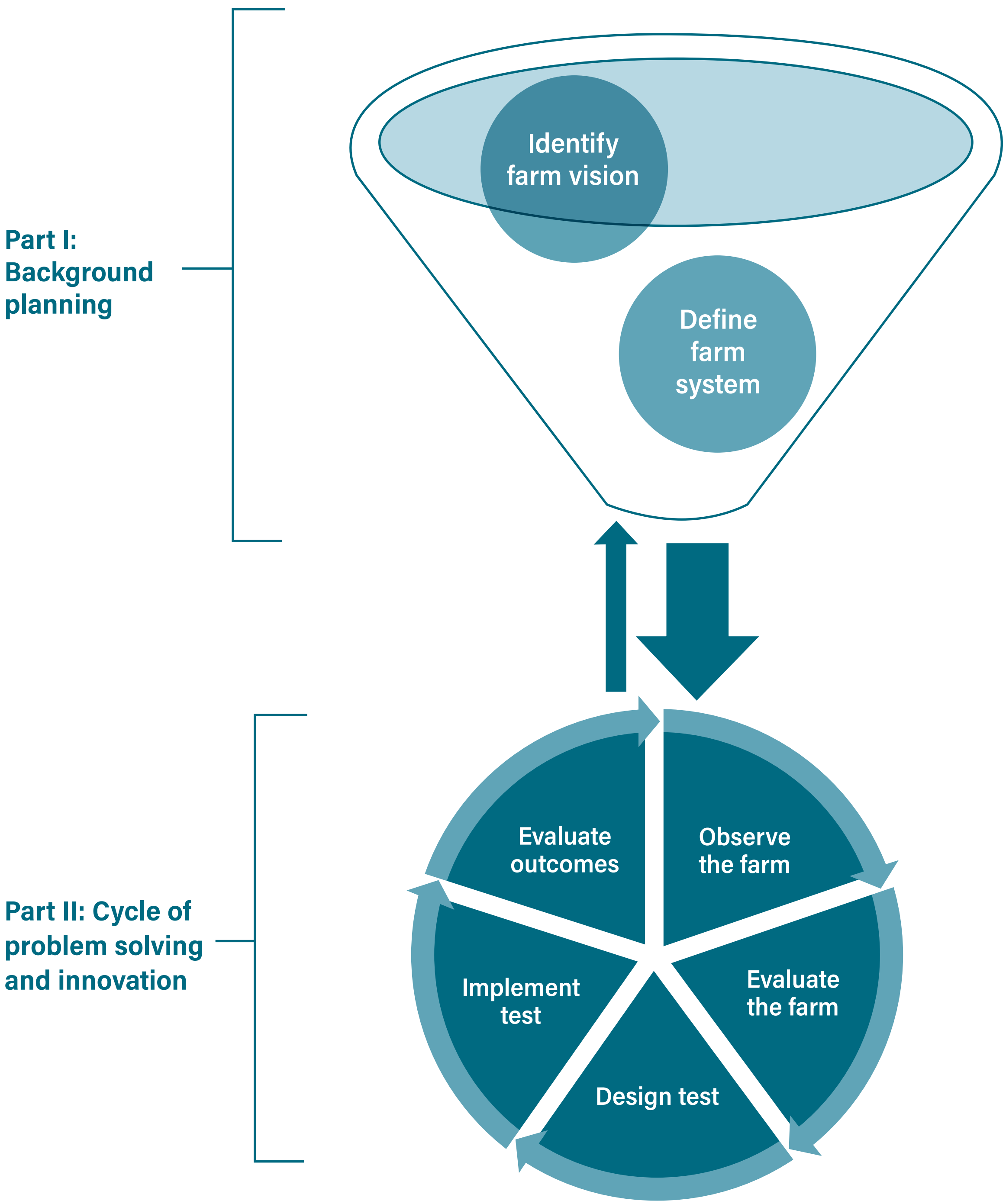
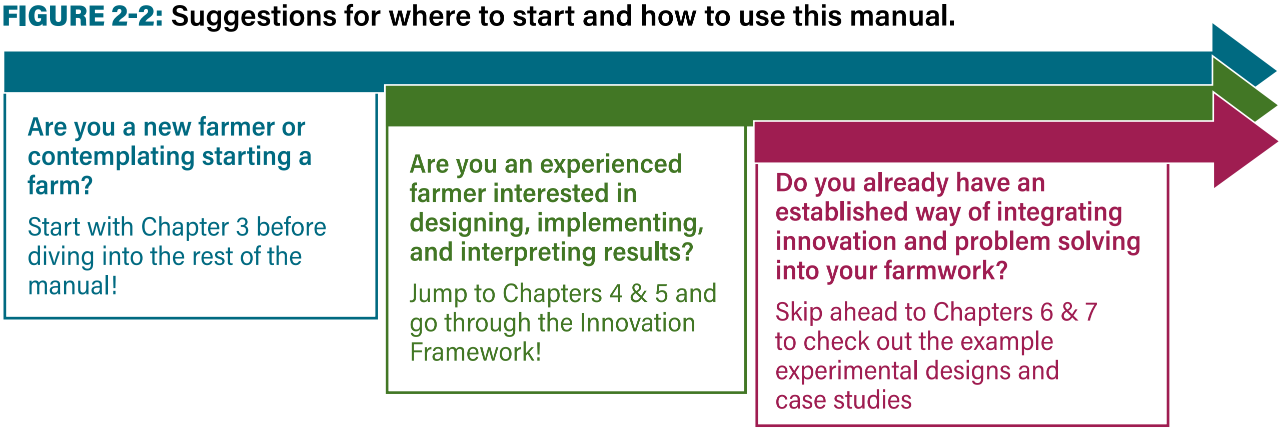


FIGURE 2-2: Suggestions for where to start and how to use this manual.



Adaptive whole farm management

To avoid reinventing the wheel, we anchored the Framework developed by the farmer focus group to the established concept of adaptive whole farm management (Figure 2-3). This cycle of problem identification, experimentation, evaluation, and adjustment is common across many forms of natural resource management, including fishing, forestry, as well as game and wildlife management. It involves multiple, continuous cycles of adjusting and evaluating farming systems on an ongoing basis to improve farm operations. The aim of adaptive management is to improve a farm system incrementally over time in response to changes, be they environmental, governmental, economic, or personal. The cycle of problem solving presented in this manual (Figure 2-4) follows the "plan", "do", and "evaluate" stages of adaptive management.

FIGURE 2-3: Diagram of adaptive management cycle (adapted from Jones [2009]).

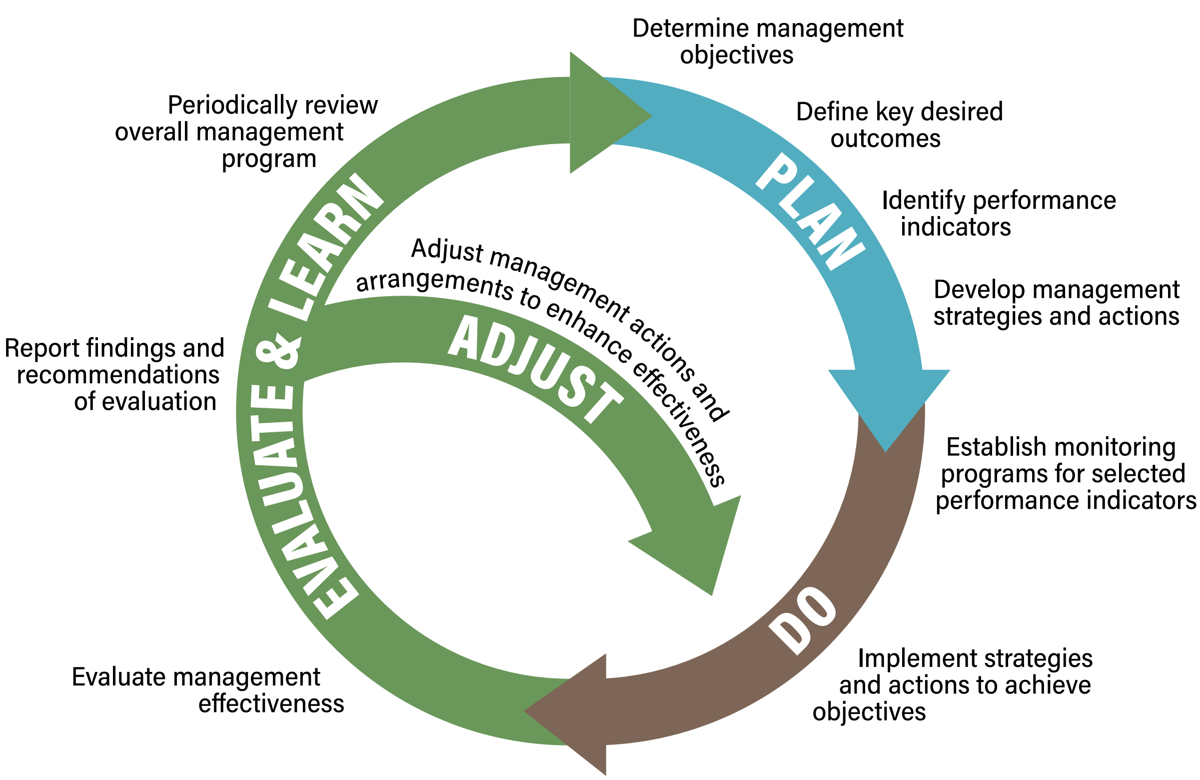
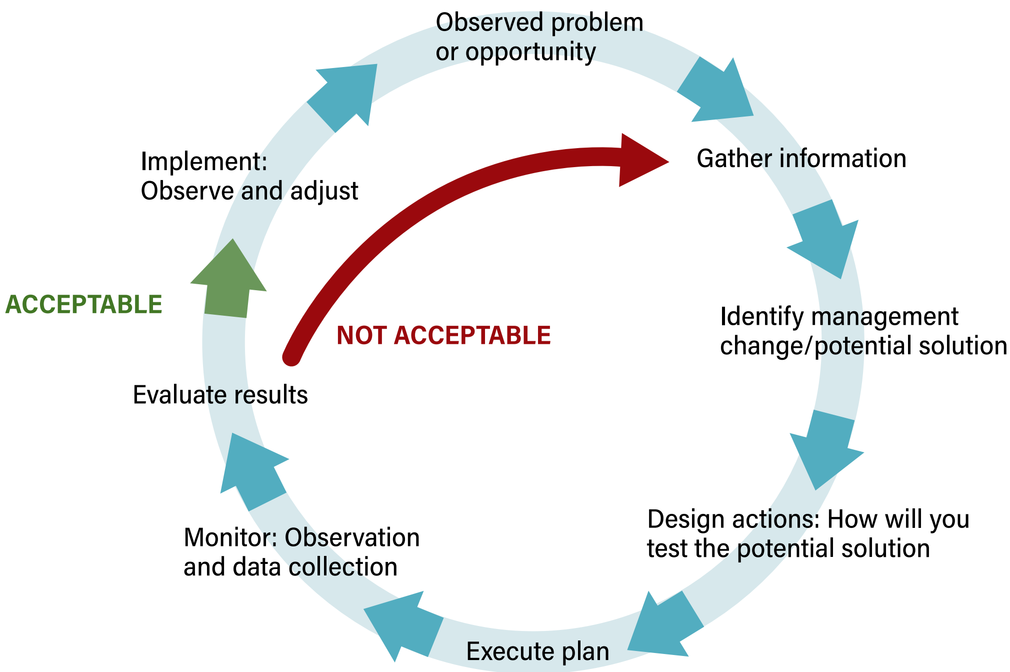


FIGURE 2-4: **Graphic illustration of the cycle of on-farm problem solving. The process begins with observing a problem or opportunity, and it continues until an acceptable result is found and implemented.**



The role of farmers in agricultural research and innovation

If adaptive management is commonly practiced in many natural resource management fields, why is it rarely taught to or used by farmers? Before the rise of land grant universities, farmers produced and shared new discoveries within the farming community through informal social networks, town meetings, and farmer organizations. Until about the mid-1950s, the role of farmers in problem solving and experimentation was widely recognized as a cornerstone of agricultural production and innovation.

The transition to industrial agriculture resulted in a shift in agricultural knowledge systems and an increased reliance on formal research and the scientific method (Box 2-1). Farmer innovation and farmer-to-farmer knowledge sharing diminished as researchers produced and provided knowledge directly to farmers. On-farm research declined, and the farmer's role was often limited to implementing researcher-designed trials or merely granting permission for researchers to install a trial on their farm.

BOX 2-1: **Comparing and contrasting informal and formal research.**

Formal research usually refers to scientific research conducted to test a hypothesis or answer a specific question. It involves systematic research and abides by the scientific method, which lays out a series of requirements for the research design. By contrast, informal research is carried out without using the scientific method. People have engaged in informal research since long before the scientific method was developed.

Experienced farmers can carry out formal, scientific research independently or by collaborating with an extension educator. However, experimental designs that meet all of the strict criteria of the scientific method are not always the best approach to problem solving and innovating on working farms. Formal and informal research are complementary, not replacements for one another. Both play a role in increasing the productivity and resilience of farm systems.

TABLE 2-2: Benefits and challenges of carrying out farmer-led research and experimentation.

Strengths/Benefits	Weaknesses/Limitations
▪ Farmers have detailed knowledge of conditions on their farms ▪ Topics investigated are relevant to farmers ▪ Management practices/technologies are evaluated within the context in which they will be used ▪ Allows for new practices to be adjusted to the particular needs of the farm ▪ Expands farmers' understanding of their farming system ▪ Empowers and stimulates innovation	▪ Farmers may have limited knowledge of or access to current science and emerging technologies ▪ Requires time, effort, and resources ▪ Imprecise data collection and monitoring methods ▪ Communication of results may be limited ▪ Fear or lack of self-confidence

Even though farmer knowledge systems may have been undervalued in formal academic institutions, informal experimentation by farmers has always been critical to successful farm management. There are many examples of innovations developed through informal farmer research, including the roller-crimper/cover crop management approaches Steve Groff (Cedar Meadow Farm, Case Study #11) adapted for North American farm systems and the complex vegetable-cover crop rotations developed by Eric and Anne Nordell (Beech Grove Farm). Conducting research while managing your farm comes with a number of benefits and limitations (Table 2-2).

The emergence of the sustainable agriculture movement challenged the knowledge system in which researchers produce technology and information and expect passive farmers to implement these technologies. The recent renewal of farmer engagement in university-led agricultural research is most evident in organic agriculture where, prior to the 1990s, farmers had to develop their own management systems. The advent of USDA research funding targeting organic production systems stimulated researcher–farmer collaborations and enabled the transmission of organic farming knowledge from farmers to university researchers. Currently, it is widely recognized that farmers are uniquely qualified to assess their own needs and priorities, as well as develop, evaluate, and implement solutions to issues arising on their farms. Table 2-3 illustrates the continuum of researcher and farmer collaborations. The focus of this manual is farmer-led research where farmers either test solutions independently or collaborate with scientists and extensionists to design and carry out trials on their farms.

Fostering problem solving and innovation

In developing this manual, we learned that successful farmer-innovators have one thing in common: they have developed systems of problem solving and experimentation that are compatible with their normal farming operations and enable them to be proactive in testing improvements.

TABLE 2-3: Gradient of farmer involvement in research; rather than merely involving farmers as consultants or asking them to implement trials designed by scientists, participatory action research places farmers on equal footing with scientists in designing and interpreting research. This manual focuses on farmer-led research.

Researcher-led		Participatory action research	Famer-led	
Independent of farmer input	Consultative: Farmer advisors	Collaborative: Farmer-scientist partnerships	Consultative: Advice from scientists	Independent

TABLE 2-4: Conditions that stymie and ease farmer experimentation.

Advantages	Barriers
▪ Years of farming in a particular place provide experience and perspective necessary for identifying and solving problems ▪ Financial stability ▪ Obvious and easily observable problems ▪ Eagerness to continually improve farming systems or try new technologies ▪ Commitment to allocate time and resources annually to continual improvement ▪ Self-confidence, curiosity, and creativity	▪ New farmers have limited experience to establish baselines and benchmarks for detecting changes ▪ A lack of resources that ensure basic stability ▪ Experienced farmers may not want to change their production systems ▪ Low commitment to farming (work commitments outside of farming) ▪ Facing a complex problem whose root cause is uncertain

We believe problem solving and innovation skills can be learned by any farmer who is interested in improving their farming operation. The first step in cultivating your innate problem-solving and innovative capacity is creating an environment in which you aren't afraid to try new things and occasionally fail (Table 2-4). While personal and financial stability increase the capacity to experiment on a farm, courage and passion for learning are the essential ingredients. We have known this central lesson since childhood, if only we remember it: get dirty, make mistakes, and have fun!

Problem solving or innovation?

Problem solving and innovation have much in common. Innovation typically involves some degree of problem solving, and problem solving can lead to the development of innovative solutions. Both are equally important aspects of managing a farm successfully. However, they can differ slightly in scope and intent (Table 2-5).

Although problem solving is a daily part of farming, this manual isn't about day-to-day troubleshooting. Instead,

TABLE 2-5: Comparing and contrasting the characteristics of problem solving and innovation on the farm. Adapted from Boersma (2013).

	Problem Solving	Innovation
Differences	▪ Reactive to address a problem ▪ Maintain the status quo ▪ Motivated to solve a particular problem ▪ Needs to be addressed as soon as possible	▪ Proactive to take advantage of opportunities ▪ Improve beyond the status quo ▪ Motivated to continuously improve the farm system as a whole ▪ Important, but not necessarily urgent
Similarities	▪ Easier to do with clear goals and measures of success ▪ Based on observing and understanding the farm system ▪ Benefit from broad background investigation and networking ▪ Rigor of experimentation reflects the risk involved ▪ Improved through methodical evaluation of results ▪ Typically repetitive, cyclical, and based on past efforts ▪ Allow you to better understand your farming system and maintain its viability	

we focus on how problem solving will enable you to steadily improve your farm and adapt to changing conditions by testing various possible solutions to find the one that best suits your needs. Many problems don't have obvious, immediate solutions, and therefore demand that you develop a new approach. Some examples of situations this manual can help you address are:

- Problems that require multiple trials because there are several possible solutions and the best option is unclear
- A solution that served you well in the past is now proving ineffective, or what worked for someone else isn't doing the same for you
- Problems that aren't widely acknowledged or understood
- Situations where the immediate problem has a known solution, but through solving this problem you see an opportunity for an innovation and substantial improvement of your farming system
- Problems that arise due to changing environmental conditions (i.e., climate change, increasing weed pressure, a pest that isn't responding to your usual measures) or changing markets/regulations that require substantive changes in your farming system
- Any improvement you want to pursue that involves a substantive change in farming practices

The types of solutions you test can run the gamut. They can be small modifications, such as variety trials, testing a change in rotation sequence or cover crop species, or modifying seeding densities or other aspects of planting practices. Alternatively, they can also be more substantive changes, such as adding a new cash crop to your operation, modifying/inventing new equipment, or substantially changing tillage intensity.

Innovation pushes beyond solving a problem to producing something entirely new that does not yet exist. Innovation can be the result of bringing together ideas or technologies in a new way to solve a problem. Alternatively, innovation can result from a more proactive process of setting a goal for improving your farming system before problems arise, and pursuing a series of steps to realize that goal. Regardless of the starting point, the process of innovation is more involved than problem solving, and usually requires more background research and several rounds of experimentation.

For example, when Lou Lego discovered that downy mildew was killing his cucumber crops, he needed to act fast to find a solution. He started with row covers—a known practice that is effective for protecting crops from foliar diseases and insect pests. While this was somewhat effective at reducing the disease, it had other drawbacks that led him to an innovative solution, described in Case Study #6.

> “Innovation pushes beyond solving a problem to producing something entirely new that does not yet exist.”

Similarly, Steve Groff's adaptation and integration of the roller-crimper into his no-till cover cropping system (Case Study #11) for growing tomatoes offers another great example of innovation. He started out with a goal of growing tomatoes while also restoring soil health and reducing chemicals. This led him to develop a no-till cover cropping system. Following this, inspired by farmers in Brazil, he modified existing equipment for a new use in order to kill the cover crop without tillage. More information on this system is available here.

3 Establish life and farm goals

There are many excellent guides for starting a farm, and we encourage those who are thinking of starting a farm or are in the process of doing so to seek guidance from these resources (Box 3-1). Likewise, guides for applying whole farm management approaches are also available in the form of books and online resources. In this chapter, we limit discussion of Steps A and B to the features most essential for farmers' success in problem solving and innovating on their own farms. For broader, more comprehensive information, please consult the resources we have listed at the end of this chapter.

Step A: Identify a farm vision

Having a clear farm vision enables the development of problem solving strategies that are compatible with current farm operations and innovations that will help you achieve your hopes for the future. Creating and revisiting such a vision will help ensure the sustainability of your farm, because a farm vision changes over the course of a lifetime.

A-1 Network with farmers

Finding a mentor or colleague can help you learn about common problems, new solutions, mistakes to avoid, and ideas for improvements. Farmer networks can be informal (e.g., neighbors, peers) or connected to a farmer-oriented NGO or private organization (e.g., Northeastern Organic Farming Association, Soybean Growers Association).

A-2 Identify quality of life requirements

What do you want out of life? What makes you happy? These deceptively simple questions are at the heart of

BOX 3-1: Reading suggestions for beginner farmers from our farmer-innovator consultants.

Here are a few books recommended for beginners. The books on this list will inform your farm management, help you clarify your business practices, and inspire you to be creative and courageous farmers.

- **Brunetti J (2014) The farm as ecosystem: Tapping nature's reservoir — biology, geology, diversity. Acres U.S.A., Austin, Texas.**
- **Fukuoka M (2009) The one-straw revolution: An introduction to natural farming. New York Review Books, New York, New York.**
- **Hartman B (2015) The lean farm: How to minimize waste, increase efficiency, and maximize value and profits with less work. Chelsea Green Publishing, White River Junction, Vermont.**
- **Montgomery DR (2017) Growing a revolution: Bringing our soil back to life, First edition. W.W. Norton & Company, New York.**
- **Penniman L (2018) Farming while Black: Soul Fire Farm's practical guide to liberation on the land. Chelsea Green Publishing, White River Junction, Vermont.**
- **Strauss SD (2012) The small business bible: Everything you need to know to succeed in your small business, 3rd ed. Wiley, Hoboken, New Jersey.**
- **Wiswall R (2009) The organic farmer's business handbook: A complete guide to managing finances, crops, and staff — and making a profit. Chelsea Green Pub, White River Junction, Vermont.**

the definition of quality of life—a broad concept that includes one's satisfaction with their health, social relationships, environment, and economic status. Establishing quality of life goals will help clarify your farm vision and determine which solutions and innovations to pursue down the road as you adapt to changing conditions and solve problems. Many questionnaires can guide you through the process of defining quality of life goals, and while they aren't the only approach, they offer concrete methods to clarify the concept and spur creative insights. It's beneficial to do this with your business partners and family to avoid tension down the line and make sure everyone involved in the farm is on the same page. Questions you can ask yourself to determine your own definition of quality of life include:

- How valuable is sharing free time with friends and family?
- How much am I willing to work on and off the farm?
- Do I enjoy working with others or by myself?
- Do I particularly enjoy specific tasks or aspects of managing my farm and business? Are there any I particularly dislike?
- How much risk am I willing to take? Do I prefer stability, or am I comfortable with uncertainty if there may be a payoff?
- How do I define financial security?
- What are my other interests/hobbies in life? How much time do I want to devote to them? What about those of my family? How do they fit into my schedule for managing the farm?
- What makes me happy? Who is important to me? Where do I want to live? How do I balance tradeoffs and priorities between these?
- Who and what am I responsible for?

A-3 Identify values and a mission

Your personal values, mission for the present, and vision for the future of your farm are the basis for all your decisions about your farm, including choosing production systems, targeting markets, and deciding on changes to implement to improve your system. Values, missions, visions, and goals are interrelated—but distinct—concepts. Identifying them may seem intuitive, but devoting time to think about and write them down can help to clarify your motivations and guide your approach to innovation and problem solving. Chaw Chang (Stick and Stone Farm) believes that you have to be brutally honest with yourself about your values and beliefs and use them as a starting point for envisioning your farm.

Values are the principles, standards, beliefs, and qualities you consider important in life. Values guide decision-making processes and are, in turn, reflective of the

decisions you make. We encourage you to grab a notebook, sit down, and take as much time as necessary to address the following questions:

- Do I have a personal ethic to which I am bound?
- How do I want to relate to other people and my environment?
- What are my fundamental, intrinsic motivations?
- How do I define success?

Your mission is focused on how your values inform decision-making. A mission statement describes the primary purpose of your farm operations. It identifies:

- The purpose of the farm
- Who performs what tasks
- What you want to provide to others, when, and to whom
- How others perceive you and your farm
- What sets your farm apart
- How you manage your farm and farm business

Having a clear set of guiding personal values and an established mission statement will help prioritize problems and identify the constraints placed on your problem-solving process. For example, Karma and Michael Glos (Kingbird Farm, Case Study #7) decided to breed their own organic chickens because one of their farm goals is to minimize external inputs and avoid dependence on conventional inputs. This goal reflects their values related to self-sufficiency and organic practices. Raising their own chicks is a costlier option compared to buying conventionally produced chicks. However, because of their values and goals, they developed a system of maintaining breeding stock and producing their own chicks through a series of on-farm trials. Other farmers who have different values and goals might decide that raising chicks organically isn't worth the effort or cost.

A-4 Articulate farm vision and goals

While a mission statement is focused on the present, a vision statement looks to the future and identifies what you would like yourself and your farm to become over time. A farm vision can be written as a narrative or represented as a diagram showing how you want your farm to develop. Questions to ask yourself to clarify your vision statement include:

- What do I like about my farm that I want to maintain? What qualities do I want to change?
- What do I want to accomplish? Are these goals material? Spiritual? Personal? Is there conflict between these objectives and, if so, how can I reconcile them?
- How much money do I want? How much do I need? Is the difference between the answers to these questions important to me?
- How do I want others to perceive me and my farm?

For example, Good Works Farm's vision is, "to be a person-centered, integrated, sustainable community where individual choice is respected, community involvement is encouraged, and independence is fostered." Here, you can see the farm's desired qualities (person-centered, sustainable, etc.), goals (fostering independence for differently-abled farmers), and how they want the farm to be perceived (one where individual choice is respected and community involvement is encouraged).

Together, the mission and vision statements will serve as the basis for your farm goals that establish concrete steps to perform to achieve your farm vision. Goals can be personal, production-oriented, or business-oriented. It's useful to have both short- and long-term goals. Having clear farm goals is essential for prioritizing and solving problems, as well as providing inspiration for innovation. To improve the probability of achieving goals, it's helpful to verify that they're SMART:

- **Specific:** Specific goals are clear and address primary questions such as: What is the end goal and why is it important? Who will participate in the work needed to achieve this goal? Where will it take place? When do you want to complete the goal?
- **Measurable:** Goals can be qualitative or quantitative (e.g., having an aesthetically satisfying farm or achieving a particular level of production, respectively). Develop some way of tracking your progress toward achieving them.
- **Achievable:** All projects have limitations and tradeoffs, so goals should be realistic and attainable. It will take some effort to determine whether a goal is too low or high, so it may be useful to identify goals that are highly aspirational as well as backup options in case any of the initial (higher) goals fail.
- **Relevant:** Choose goals that relate directly to your actual vision for your farm, not what you think your vision ought to be based on someone else's' standard. It's also important to focus on goals that you can actually control and aren't entirely dependent on external factors like weather or prices.

- **Time-bound:** Establish deadlines for goals. Identify goals that are short-term (1–6 months), mid-term (1–5 years), and long-term (>5 years), as well as intermediate objectives for mid- and long-term goals that can be used as checkpoints to assess progress.

A-5 Identify a target market

While farms aren't just businesses, they're still businesses. Therefore, finding a suitable market is essential for success, and it follows that the markets you target will play a large role in driving the kinds of solutions and innovations you can pursue (Figure 3-1).

Many resources compile market data; one that can be useful to farming businesses is the United States Small Business Administration. Using readily available data (e.g., interest rates, consumer demographics) can be quick and relatively straightforward, but the data may not reflect local markets or unique goods and services comparable to what you provide. Gathering your own market data (e.g., number of consumers, average purchase price of goods) may require time and effort, but the results will likely be more accurate and applicable to your unique situation. This information will be more useful in guiding decisions about what you can improve or change the most.

FIGURE 3-1: Determining your target audience can have implications on how you market your farm products.

© Mike Baldwin / Cornered

"We cater to city folk."

BOX 3-2: How to use Purdue University's Agricultural Economics INventure Business Planner to generate a business plan.

1. **Visit https://www.purdue.edu/newventure.**
2. **Sign up for a new account if you are a first-time user. Repeat users will be able to log in directly with their previously established credentials.**
3. **Click the "New" button.**
4. **Enter your farm's information into the fields in the pop-up (e.g., farm name, phone number, address).**
5. **Click on the first step (i.e., "Why do you want to begin this venture?") if beginning a new business plan. If returning to an existing plan, click on whichever step you want to revise.**
6. **Enter your responses to the resulting prompts into the corresponding text boxes. Additional information—including definitions, examples, and additional resources—can be found in the left margin of the page. Click the "Save" button in the top center of the page if you want to leave the plan incomplete and return to it at a later time.**
7. **Click the "Next" button to advance to the next step and set of prompts.**
8. **Continue until you have responded to all prompts.**
9. **After finishing all of the prompts, save your responses, and click the "Main Menu" button. Verify that all of the steps have been completed and click the "Generate Report" button at the top of the Main Menu page.**
10. **Click "Generate Report" on the next page. The compiled business plan will download automatically as a Microsoft Word document, which you can edit further.**

Your target market may change, either as a result of shifting demographics, changes in consumer preferences, or personal circumstances. For example, Pat and Mike Kane (Shamrock Hill Farm) had run a CSA for many years, but Pat's new off-farm job at the Accredited Certifiers Association prevented her from helping Mike around the farm as much as she had in past years. In order to maintain a work/life balance that ensured the quality of life they wanted, Mike and Pat ultimately decided to stop running the CSA and focus on direct bulk sales of produce and beef despite their efforts to keep the CSA program afloat.

A-6 Write a business plan

A business plan will help identify the limitations of a farm's finances; it doesn't make sense to attempt what you can't afford. It will also help identify which problems and opportunities you can address to increase your profits the most. This document is crucial for evaluating the financial effects of management decisions, identifying potential market strategies and opportunities, and communicating information that determines the financial viability of a farm to potential lenders and partners. While it's beyond the purview of this manual to describe how to write a business plan, we provide a list of resources at the end of this chapter and offer some additional details in Box 3-2. Additionally, Greenway Farms LLC has provided a sample business plan, which is viewable here.

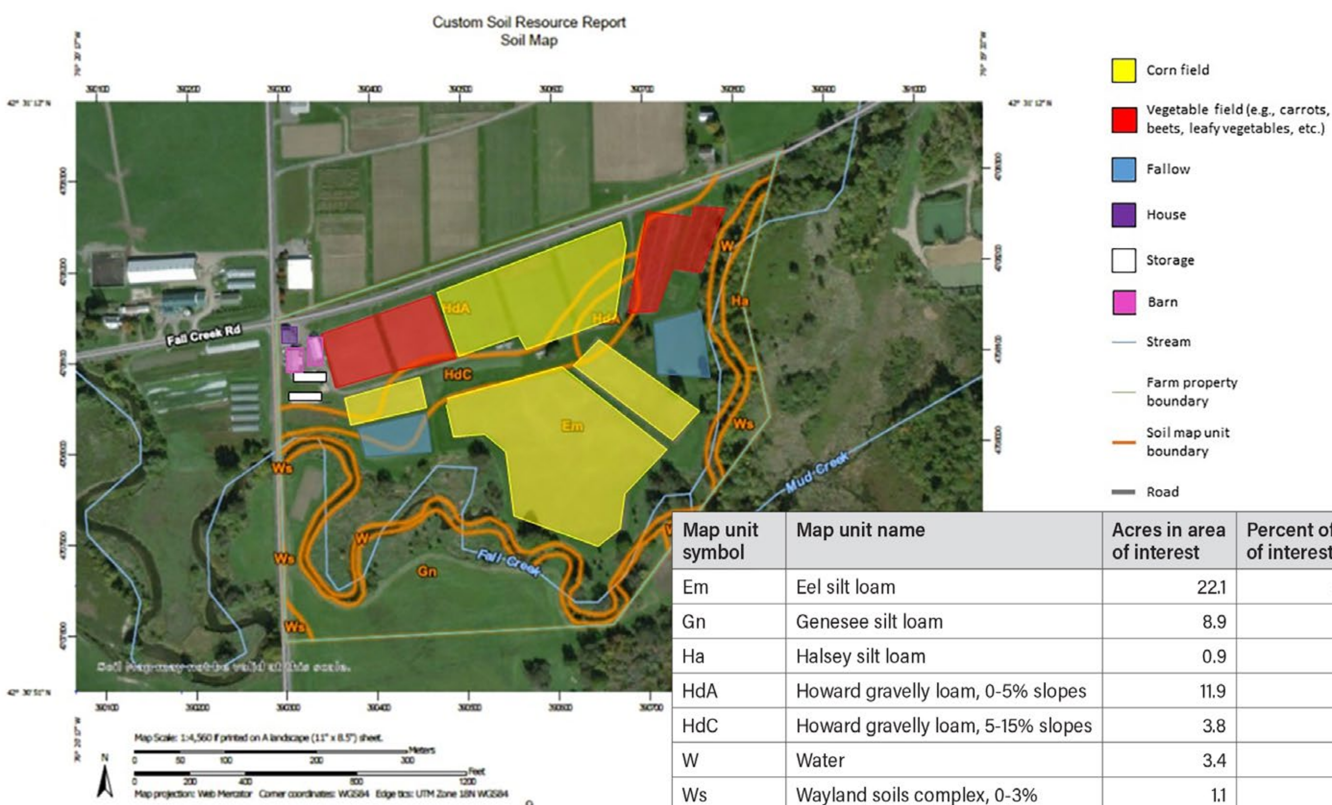
Step B: Define the farm system

B-1 Map the Farm

Regularly remapping a farm offers a bird's-eye view (Figure 3-2) that can reveal changes you might not notice from the ground. For example, Luke Gianforte (Gianforte Farm) used drone imagery to assess crop health, which helped him identify patches within his fields that performed poorly year after year. In some cases, the conclusions he drew from these images led him to stop renting particular fields altogether.

Obtaining digitally rendered and/or geospatially referenced maps may ensure accuracy, but this can be

FIGURE 3-2: Example farm map with soil and land use/cover data from the National Resource Conservation Service soil mapper (Box 3-5).



Map unit symbol	Map unit name	Acres in area of interest	Percent of area of interest
Em	Eel silt loam	22.1	42.5%
Gn	Genesee silt loam	8.9	17%
Ha	Halsey silt loam	0.9	1.7%
HdA	Howard gravelly loam, 0-5% slopes	11.9	22.8%
HdC	Howard gravelly loam, 5-15% slopes	3.8	7.2%
W	Water	3.4	6.6%
Ws	Wayland soils complex, 0-3% slopes, frequently flooded	1.1	2.1%

BOX 3-3: Instructions for using Google Earth to acquire satellite imagery for maps.

1. **Visit www.google.com/earth and download the desktop program. There is an online version, but it lacks many of the features to perform the steps listed below.**
2. **Type your address into the search bar near the top left of the screen and click the search button. The map will then zoom to your farm.**
3. **You can click and drag the map to change your position. Zoom in and out using the scroll wheel on your mouse or using the +/- buttons near the top-right of the screen. Zooming can change the angle of the imagery, so press the "r" key on your keyboard to get a perpendicular view.**
4. **You can add points and shapes by clicking the respective buttons on the toolbar at the top of the screen. For instance, in Figure 3-1, the farmer added polygons to denote different cropping systems for different fields.**
5. **Print maps by clicking File>Print. You can edit the title and legend by clicking on them when the map print preview appears on screen. Once you are satisfied with the map, click "Print..." or "Save as PDF..." in the toolbar that appears near the top of the screen.**

expensive, and processing software tends to have a steep learning curve. A hand-drawn map can meet most needs if it's more or less to scale. An intermediate alternative would be to print satellite imagery from Google Earth and draw in additional details (Box 3-3).

Note the area of different fields, and label physical features such as water bodies, land cover, structures, and topography. In addition, consider the history of the farm, including past farm management, yields, and results from soil testing and whether regulations regarding management differ across the property. The United States Department of Agriculture Natural Resources Conservation Service Web Soil Survey provides freely downloadable soil maps that include information such as geography; descriptions of soil types; and biophysical characteristics such as cation exchange capacity, water retention, and organic matter (Box 3-4). The data presented along with these maps may not accurately reflect conditions on the ground, so we suggest comparing the data with your own observations.

Sometimes, besides documenting the locations of resources, the very act of mapping a farm can help identify the cause of a problem. For example, Klaas Martens (Lakeview Organic Grain, Case Study #5) had been fertilizing his fields with manure from a nearby dairy when he noticed that weed populations were substantially greater in particular areas of his farm. When he mapped the fields with the worst weed problems, he concluded they had one thing in common: their close proximity to the barn where the manure was stored. He realized they were probably receiving more manure compared to fields more distant from the barn, introducing more weed seeds and creating higher nutrient levels that enabled weed growth. This led him to be more careful about distributing manure more evenly across his farm.

B-2 Perform a resource inventory

A resource inventory (Appendix II) can provide you with information about your farm's current shortcomings and the resources available to address them. The farm map identifies available natural resources, such as soils and water. Other features to consider in your resource inventory include livestock, equipment, and infrastructure. Inventories of financial resources can include liquid assets such as checking and savings accounts, investments, and real estate. Consider human resources, making note of skills and availability. Finally, it can be helpful to identify people who you can turn to for help beyond your farm, like your Soil and Water Conservation District, extension, and United States Department of Agriculture National Resource Conservation Service representatives. Have your written goals/mission statement nearby, and consider how each part of the resource inventory aligns with your goals.

An alternative to a resource inventory is a Strength-Weakness-Opportunity-Threat (SWOT) analysis (Table 3-1). This analysis evaluates asset availability (or lack thereof) and determines how these resources can be used to improve farm function, resilience, and sustainability. The sample business plan from Greenway Farms LLC includes a SWOT analysis that can serve as an

TABLE 3-1: **Strength-Weakness-Opportunity-Threat (SWOT) analysis framework. Consider each bullet point for the unique situation of each particular farm.**

Strengths	Weaknesses	Opportunities	Threats
▪ Knowledge, skills, and experience of farm team ▪ Infrastructure (buildings, equipment) ▪ Environmental resources (soils, water, etc.) ▪ Certifications ▪ Financial resources	▪ Limitations of property (e.g., poor soil fertility, limited water access) ▪ Old or damaged equipment and structures ▪ Market limitations ▪ Gaps in farm team abilities ▪ Regulatory constraints	▪ Emerging markets ▪ Education/extension programs ▪ Business partnerships ▪ New technologies and management strategies ▪ Grant and funding opportunities	▪ Rising input costs ▪ Price volatility ▪ Environmental factors (e.g., erosion, climate change, flooding)

BOX 3-4: **Instructions for using the United States Department of Agriculture Natural Resources Conservation Service Web Soil Survey to generate soil maps and obtain soil information.**

1. Visit the soil survey website and click the green "Start WSS" button.
2. You will define your area of interest (AOI) in the resulting window.
   a. Click the button. Then, using the crosshairs on the map, click and drag to create a box that includes your farm area. The map will zoom to the area you selected.
   b. Repeat this step until you have located your farm and defined the extent of the map window to display the appropriate scale/level of detail.
   c. You can pan in the map using the button or zoom out using the button.
   d. Click the "AOI by Rectangle" to establish a rectangular AOI by clicking and dragging the crosshairs in the map as you did to zoom. Alternatively, click "AOI by Polygon" to create an irregular AOI by clicking individual points using the map crosshairs that will serve as corners of the shape. Double-click to close the shape area.
3. After selecting an AOI, click the "Soil Map" tab at the top of the window. This will display the soil map of the AOI, along with the soil types and their total area.
   a. You can access a description of the soil types by clicking on their names in the left-hand panel.
   b. You can print the resulting map by clicking the "Printable Version" button at the top-right corner of the window and then clicking the "View" button in the resulting pop-up. This will produce a PDF of the soil map that you can save to your computer or print.
4. You can also access data regarding other soil properties for your farm by clicking the "Soil Data Explorer" tab at the top of the window.
   a. The left-hand panel lists several agricultural land-use guidelines (e.g., susceptibility to compaction, organic matter depletion) under the Soil Health heading.
   b. Clicking the "Soil Properties and Qualities" tab at the top of the map will allow you to determine various soil chemical and physical properties (e.g., calcium carbonate, organic matter, pH) measured as part of the National Resources Conservation Service soil mapping efforts. These coarse estimates cannot replace actual field measurements.

example. They have considered how their internal strengths can exploit external opportunities through innovative changes to their farm system, as well as how their internal weaknesses can be addressed to respond to external threats, lest they become problems.

B-3 Develop a whole farm plan

All the work and consideration described in the previous tasks are brought together through whole farm planning: a process by which farmers balance their quality of life needs, the farm's resources, financial limitations and requirements, and sustainable environmental stewardship. We list several examples of whole farm planning frameworks in the resources section at the end of this chapter. Similarly, many tools including software, workshops, and workbooks are available to facilitate whole farm planning.

The general process of whole farm planning involves four major steps:

1. Setting goals
2. Performing a farm inventory
3. Developing and implementing actionable management plans
4. Monitoring progress and reevaluating goals

A web diagram is one way to track farm operations over time and determine how close you are to meeting your goals. This diagram considers multiple categories, each of which correspond to your farm vision and goals. Figure 3-3 shows a rose diagram for Northland Sheep Dairy (Marathon, NY). The categories that Karl North used to define farm sustainability changed in different ways over time. For example, he found that sheep health and labor efficiency were typically not big problems, but

FIGURE 3-3: Northland Sheep Dairy sustainability illustrated in a rose diagram. The different lines represent different years when the farm's sustainability was assessed. For example, input self-sufficiency improved from 1992 to 1997, but then fell in 2002. On the other hand, labor efficiency improved continuously. Copied from the Magazine on Low External Input and Sustainable Agriculture.

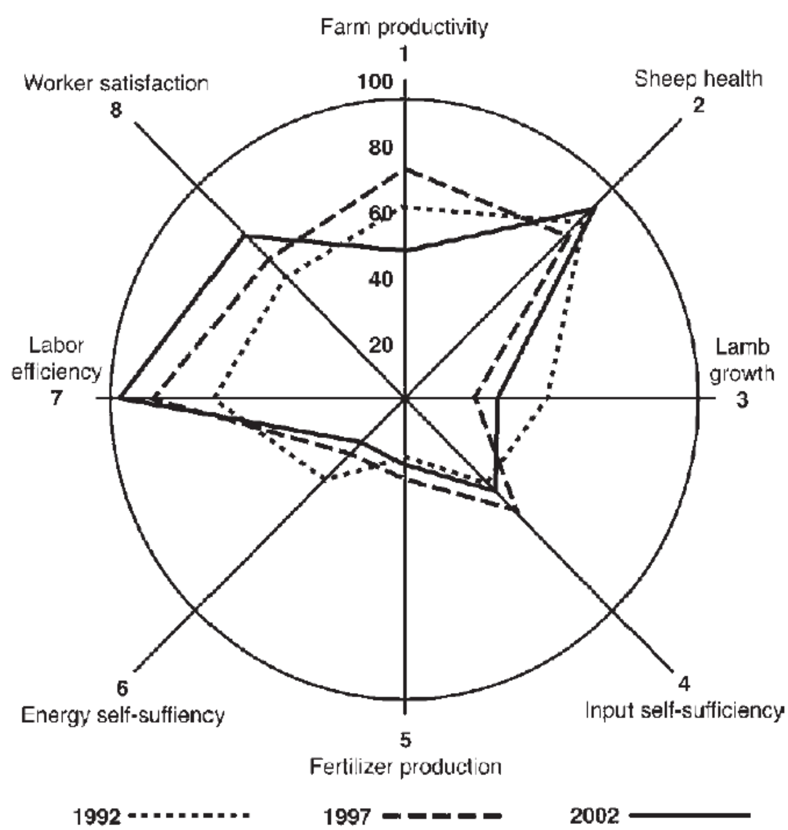


FIGURE 3-4: **Example supply chain analysis for a commercial forage production system.**

Input supply		
Agents	**Inputs**	**Output**
▪ Farmers ▪ Seed dealers	▪ Seeds	▪ Seeds for fodder producers

Production		
Agents	**Inputs**	**Output**
▪ Farmers ▪ Farmworkers	▪ Labor ▪ Land ▪ Equipment and fuel ▪ Water ▪ Fertilizer	▪ Cultivated fodder crops

Processing		
Agents	**Inputs**	**Output**
Farmers Farmworkers	Labor Equipment and fuel	▪ Harvested and baled fodder

Retailing		
Agents	**Inputs**	**Output**
▪ Farmers ▪ Wholesalers	▪ Labor ▪ Marketing	▪ Fodder for distribution to livestock operations

Consumption		
Agents	**Inputs**	**Output**
▪ Farmers ▪ Farmworkers ▪ Veterinarians	▪ Baled forage ▪ Labor ▪ Water ▪ Medicine and veterinary services ▪ Animal housing	▪ Livestock and livestock products

lamb growth and energy self-sufficiency tended to get worse over time. This allowed him to focus his problem-solving and innovation efforts on those farm operations.

Whole farm planning offers several benefits that make it useful for solving on-farm problems. The process builds on and contributes to farmers' knowledge of their farms, allowing it to accommodate the needs, desires, and resources of individual farmers. Whole farm planning also takes a broad perspective to consider how the farm interacts with its surrounding environment and whether changes might have positive or negative ripple effects. It's also a good idea to revisit your whole farm plan regularly (every few years) to ensure that it's up to date.

B-4 Determine production systems

Having a clear plan for farm management will determine the details of crop production systems (e.g., rotations, planting, harvesting, fertilization, pest control, product storage, tillage, irrigation). Decisions regarding farm production systems influence innovation and problem solving by limiting potential options as you try to improve your farming operation. To proactively identify emerging problems and opportunities, you need a functioning farm to start with. Because this is such a broad topic, we list additional resources that address the details of farm production at the end of this chapter.

B-5 Determine farm interactions

Understanding the interactions between your farm and its surroundings influences how you go about solving problems or embarking on innovations. Supply chain analysis (Figure 3-4) is one way to determine how your farm system interacts with your community and environment. This involves making a diagram of material flows in and out of your farm. Farmers who are visual learners find them extremely useful in organizing their thoughts. While these analyses can inform decision making, they may be most useful as a tool for brainstorming about how your farm interacts with other systems. Some farmers prefer to simply consider a series of conceptual questions to identify the interactions and flows into and out of their farms. An easy way to do this is to list farm inputs and outputs. Where are they coming from or going to? How reliant is your farm on those inputs? How reliant are others on your farm's outputs?

Recommended resources

Innovation inspiration

- Albrecht WA (2011). The Albrecht Papers. Acres U.S.A., Greely, Colorado.
- Boersma R (2013). Innovation in a Box. Juice Inc.
- Brunetti J (2014). The farm as ecosystem: tapping nature's reservoir. Acres U.S.A., Greely, Colorado.
- Fukuoka M (2009). The one-straw revolution: An introduction to natural farming. New York Review Books, New York.
- Hartman B (2015). The lean farm: How to minimize waste, increase efficiency, and maximize value and profits with less work. Chelsea Green Publishing, White River Junction, Vermont.
- Howard, A (1940). An Agricultural Testament. Oxford University Press, Oxford, UK.
- King FH (2004). Farmers of Forty Centuries: Organic Farming in China, Korea, and Japan. Dover Publications, Mineola, New York,
- Montgomery DR (2017). Growing a revolution: Bringing our soil back to life, First edition. W.W. Norton & Company, New York.
- Penniman L (2018). Farming while Black: Soul Fire Farm's practical guide to liberation on the land. Chelsea Green Publishing, White River Junction, Vermont.
- Turner, N (1951). Fertility Farming. Acres U.S.A., Greely, Colorado.
- Turner, N (1951). Fertility Pastures. Acres U.S.A., Greely, Colorado.
- United States Department of Agriculture (1938). Soils and Men Yearbook of Agriculture 1938. United States Department of Agriculture, Washington, District of Columbia.

Quality of life assessments

- Assessment of Quality of Life. (n.d.). Accessed 5 Sept 2019.
- Diener E, Emmons R, Larsen R, Griffin S (1985). Satisfaction with Life Scale. Journal of Personality Assessment.
- Dupuy H (1984). The Psychological general Well-Being (PGWB) Index. In: Assessment of Quality of Life in clinical trials of cardiovascular therapy. Le Jacq Publishing, pp 170–183.

- Henrich G, Herschbach P (2000). Questions on Life Satisfaction (FLZM) - A Short Questionnaire for Assessing Subjective Quality of Life. European Journal of Psychological Assessment 16:150–159.

Vision and mission statements

- Brumfield, R. G., & Komar, S. (2012). Developing a Mission/Vision Statement for your Farm. Rutgers New Jersey Agricultural Experiment Station.
- Grusenmeyer, D. (2009). Mission, Vision, Values & Goals. PRO-DAIRY.
- Riesselman, L. (2015). Business Plan: Values, Vision, Mission, and Goals. Presented at the Hort/Ag EdS 465, Iowa State University.

Business plans

- Agriculture Business Plan Sample. (2018, May 1). Entrepreneur Magazine.
- Beale, B., Dill, S., Johnson, D., & Myers, G. S. (2008). Farm Business Planning. College Park, MD: The University of Maryland Extension.
- DiGiacomo, G., King, R., & Nordquist, D. (2003). Building a Sustainable Business: A Guide to Developing a Business Plan for Farms and Rural Businesses. The Minnesota Institute for Sustainable Agriculture and Sustainable Agriculture Research and Education.
- Ehmke, C., & Akridge, J. (2005). The Elements of a Business Plan: First Steps for New Entrepreneurs (No. EC-735). Purdue Extension Agricultural Innovation & Commercialization Center.
- INventure Business Planner. Accessed 13 Mar 2019.
- Shanks, J. (2016). The Farmer's Office Tools, Tips and Templates to Successfully Manage a Growing Farm Business. La Vergne: New Society Publishers.
- Strauss SD (2012). The small business bible: everything you need to know to succeed in your small business, 3rd ed. Wiley, Hoboken, N.J
- Thistlethwaite, R. (2012). Farms with a future: creating and growing a sustainable farm business. White River Junction, Vt: Chelsea Green Pub.
- Wiswall, R. (2009). The organic farmer's business handbook: a complete guide to managing finances, crops, and staff—and making a profit. White River Junction, VT: Chelsea Green Pub.

Whole farm planning

- Huelsman, M. F. (2008). Organic Whole Farm Planning Workbook. Ohio Agricultural Research and Development Center of The Ohio State University.
- Joughin, B. (2009). Whole Farm Plan Guide. The Land Conservancy of BC and FarmFolk/CityFolk.
- Kemp, L. (1996). Successful Whole Farm Planning. The Minnesota Project.
- Marrison, D. L. (2007). Whole Farm Planning Model. The Ohio State University Extension.
- Martin, D., & Fery, M. (2011). Growing Farms: Successful Whole Farm Management Planning Book (No. EM 9073). Oregon State University.
- Mulla, D., Everett, L., & DiGiacomo, G. (2011). Introduction to Whole Farm Planning: Combining Family, Profit, and Environment. Minnesota Institute for Sustainable Agriculture.

Mapping resources

- Google Earth. Accessed 13 Mar 2019.
- Web Soil Survey. Accessed 13 Mar 2019.

Means of production

Soil management

- Al-Kaisi, M., & Kwaw-Mensah, D. (2017). Iowa Soil Health Management Manual (No. 3090A). Iowa State University Extension and Outreach.
- Cranfield University National Soil Resources Institute. (2001). A Guide to Better Soil Structure.
- Manitoba Agriculture, Food, and Rural Initiatives. (2008). Soil Management Guide.
- Moebius-Clune, B. N., Moebius-Clune, D. J., Gugino, B. K., Idowu, O. J., Schindelbeck, R. R., Ristow, A. J., … Abawi, G. S. (2017). Comprehensive Assessment of Soil Health. Ithaca, NY: Cornell University.
- Zero Tillage Farmers Association. (2011). Beyond the Beginning: Zero Till Evolution. Manitoba.

Weed management

- Michigan State University Extension. (2018). Weed Control Guide for Field Crops (No. E0434).
- Peachey, E. (n.d.). Pacific Northwest Weed Management Handbook. Corvallis, OR: Oregon State University.
- Penn State Extension. (2018). Mid-Atlantic Field Crop Weed Management Guide (No. AGRS-136).

Planting

- Clark, A. (2012). Managing Cover Crops Profitably. Sustainable Agriculture Research and Extension.
- Food and Agriculture Organization of the United Nations and Technologies and Practices for Smallholder Farmers. (2015). Training Manual for Organic Agriculture.
- Mohler, C. L., & Johnson, S. E. (2009). Crop Rotation on Organic Farms: A Planning Manual (No. NRAES-177). Ithaca, NY: National Resource, Agriculture, and Engineering Service.

Nutrient management

- Homenauth, O. (2013). Fertilizer Manual. National Agricultural Research & Extension Institute.
- Magdoff, F., & Van Es, H. (2009). Building Soils for Better Crops: Sustainable Soil Management. Sustainable Agriculture Research and Extension.
- Mid-Atlantic Regional Water Program. (2006). The Mid-Atlantic Nutrient Management Handbook (No. MAWP 06-02).

Pest management

- Maryland Department of Agriculture. (2010). Integrated Pest Management in Schools: IPM Training Manual. Annapolis, MD.
- Randall, C. (1998). General Pest Management: A Guide for Commercial Applicators (No. E-2048). Michigan State University Extension.
- Randall, C. (2013). Integrated Pest Management Training Manual. Lansing, MI: Michigan Department of Agriculture and Rural Development.

Water management

- Ross, E. A., & Hardy, L. A. (1997). Irrigation Guide. United States Department of Agriculture National Resources Conservation Service.
- Shock, C. C. (2013). Drip Irrigation: An Introduction (Sustainable Agriculture Techniques No. EM 8782). Oregon State University Extension Service.
- Westside Resource Conservation District and Center for Irrigation Technology. (2004). A Technical Advisor's Manual: Managing Agricultural Irrigation Drainage Water.

Organic management

- Bradley, F. M., Ellis, B. W., Phillips, E., & Rodale Press. (2009). Rodale's ultimate encyclopedia of organic gardening: the indispensable green resource for every gardener. Emmaus, Pa.: Rodale.
- Fortier, J.-M. (2014). The market gardener: a successful grower's handbook for small-scale organic farming. Gabriola Island, BC: New Society Publishers.
- Hansen, A. L. (2010). The organic farming manual: a comprehensive guide to starting and running a certified organic farm. North Adams, Mass.: Storey Pub.
- Pieters, A. J. (1927). Green manuring: organic principles and practices.

Harvesting and storage

- Hodges, R., & Stathers, T. (2012). Training Manual for Improving Grain Postharvest Handling and Storage. United Nations World Food Programme.
- Kitinoja, L., & Kader, A. A. (2015). Small-scale Postharvest Handling Practices: A Manual for Horticultural Crops (Postharvest Horticulture Series No. 8E). Davis, CA: University of California, Davis PostHarvest Technology Research and Information Center.

4 Identifying problems and opportunities

The tasks described in this chapter depend on the outcomes of the whole farm and business planning processes described in Chapter 3. The two steps we present here contain tasks that are extremely flexible in terms of their timing and frequency, so there is no reason to view them as sequential activities. Rather, try to seamlessly weave them into your normal farming activities to reduce the effort required to perform these tasks.

Step C: Observe and gather information on the farm system

The process of mindful, ongoing observation will enable you to be proactive in solving emerging problems before they become serious.

C-1 Walk the farm

Farms are complex, dynamic systems. Experienced farmers agree that walking the farm is essential for keeping track of fields, soils, crops, and animals that make up your farming system. Some choose to set aside a specific block of time at regular intervals to walk the farm, while others find it easier to make observations as they arise during the course of farm operations. Ultimately, any approach will have pros and cons; the important thing is that you develop a strategy for systematic observation that works for you.

C-2 Record observations and events

Memories are fallible, and most people find that their recollections become less accurate over time. Therefore, although some farmers are able to rely on memory for effectively spotting problems as they develop, the majority of farmers we interviewed remarked that keeping some sort of record to document their observations was crucial to illuminating patterns and trends.

Experienced farmers use a variety of different systems for record keeping, including photographs, noting harvests on a calendar, and journaling (Box 4-1). Curtis

BOX 4-1: Tips for making and recording farm observations.

- Carry a small notepad you can use for writing down observations in the field, and then transfer the contents of these notebooks to a more permanent location, like a journal or computer document.
- If you notice something unusual, make note of it and return soon to verify your observation.
- Take time-stamped pictures of fields, crops, and soils at regular intervals to document gradual changes between seasons. It can help to take photos from the same position. Alternatively, photographs can be used to compare spatially distinct areas on the farm. Include notes on the weather, management, and other conditions along with these photos.
- Enlist the help of others who work on the farm to notice changes and communicate their observations to you.
- Discuss observations with others—family members (e.g., through conversations over dinner), other farmers (e.g., at twilight meetings), or extension educators or researchers (e.g., at farming conferences).
- Keep things organized. All the notes in the world aren't going to help if they're scattered between different sources and out of order. At the very least, date photos and notes. Some farmers use software like Evernote to create a sharable, searchable file.
- While Excel spreadsheets and specialized agricultural record-keeping software (e.g., Tend) can help organize and analyze data to inform management, it's only useful if you actually collect the data. The more you can automate your data collection, the more of it you are likely to have, and the more useful it is likely to be.
- Smartphones have opened up a whole new world of opportunities for farmers. They can be used to receive weather alerts, take photos in the field, and look up information (e.g., weed and pest identification).
- Many farmers use GPS technology that is a part of their farming operations for record keeping. For example, equipment can be outfitted with GPS tracking technology to record tillage passes and monitor yields. Although the upfront costs may be high, automatically collecting all that data is much easier than doing it manually.
- Livestock farmers in particular emphasize having a comprehensive database system to keep track of multiple data streams, including milk production, somatic cell counts, mastitis, butter fat, platelet counts, etc.

Stone (Green City Acres), for instance, prefers to use spreadsheets to ensure they don't get lost and to keep his observations organized. On the other hand, Eric and Anne Nordell (Beech Grove Farm) use photography (Figure 4-1) combined with careful record keeping of the time/location of the image as a key strategy to document changes in their farming system. They do this by taking pictures of their fields every year at the same point in the growing season in order to record how their system is performing from year to year. If they're testing a specific management practice such as a new cover crop, they take pictures more frequently to document the practice over the course of the growing season (e.g., at different growth stages).

FIGURE 4-1: Taking photos can be an effective way to record and store observations. Here, the camera lens cap serves as a way to gauge the broccoli crown size.

C-3 Observe patterns

Discoveries often start with "that's weird" rather than "eureka!". Looking for patterns in plant health and animal behavior is a good way to identify problems and

opportunities for improvements. Identifying these trends will allow you to forecast potential problems before they affect your farm. It's far less risky and requires fewer resources to nip an emerging trend in the bud before it blossoms into a problem. Likewise, you can identify possible opportunities for innovation. Patterns and trends can be indicative of how your farm is changing, and these changes can be positive (e.g., gradual declines in insect pest populations) or negative (e.g., increasing weed pressure).

Noticing patterns requires familiarity with the typical conditions on your farm (Box 4-2) and can uncover unexpected solutions to existing problems. With practice and experience, your ability to notice and understand the significance of these patterns will improve. This is particularly true for slow changes that can accumulate over many years but ultimately result in large changes that cause problems. Soil degradation is a prime example of how gradual changes can ultimately cause serious problems, such as a reduction in yield. Dave and Meg Schmidt (Troublesome Creek Cattle Co.) offer an example of how to track subtle patterns. To minimize costs, the Schmidts monitored feeding on their grass-fed cattle farm. They tracked the weights of their animals, as well as the amount and value of the feed they consumed, over three years to determine the "normal" range of values they could expect. These data showed them they could diversify their feed during winter months to cut costs.

Identifying significant weather patterns will be increasingly important as a result of climate change. Although local weather stations can help with regional forecasting, many of these stations are located in urban environments where weather conditions can differ considerably from those of rural areas. As technology becomes more affordable, farmers are increasingly installing their own on-farm weather stations to provide real-time weather information. This investment will also enable you to accurately track multi-year and decadal weather patterns. A wide assortment of weather stations, varying in function and cost, are available. Choosing the system that is right for you will depend on your available financial resources, the variables you want to measure (e.g., wind speed, air pressure, precipitation, soil temperature, air temperature, etc.), and whether or not you are interested in automating data collection and storage. We provide some additional guidance on this topic in Appendix IV.

C-4 Perform routine testing

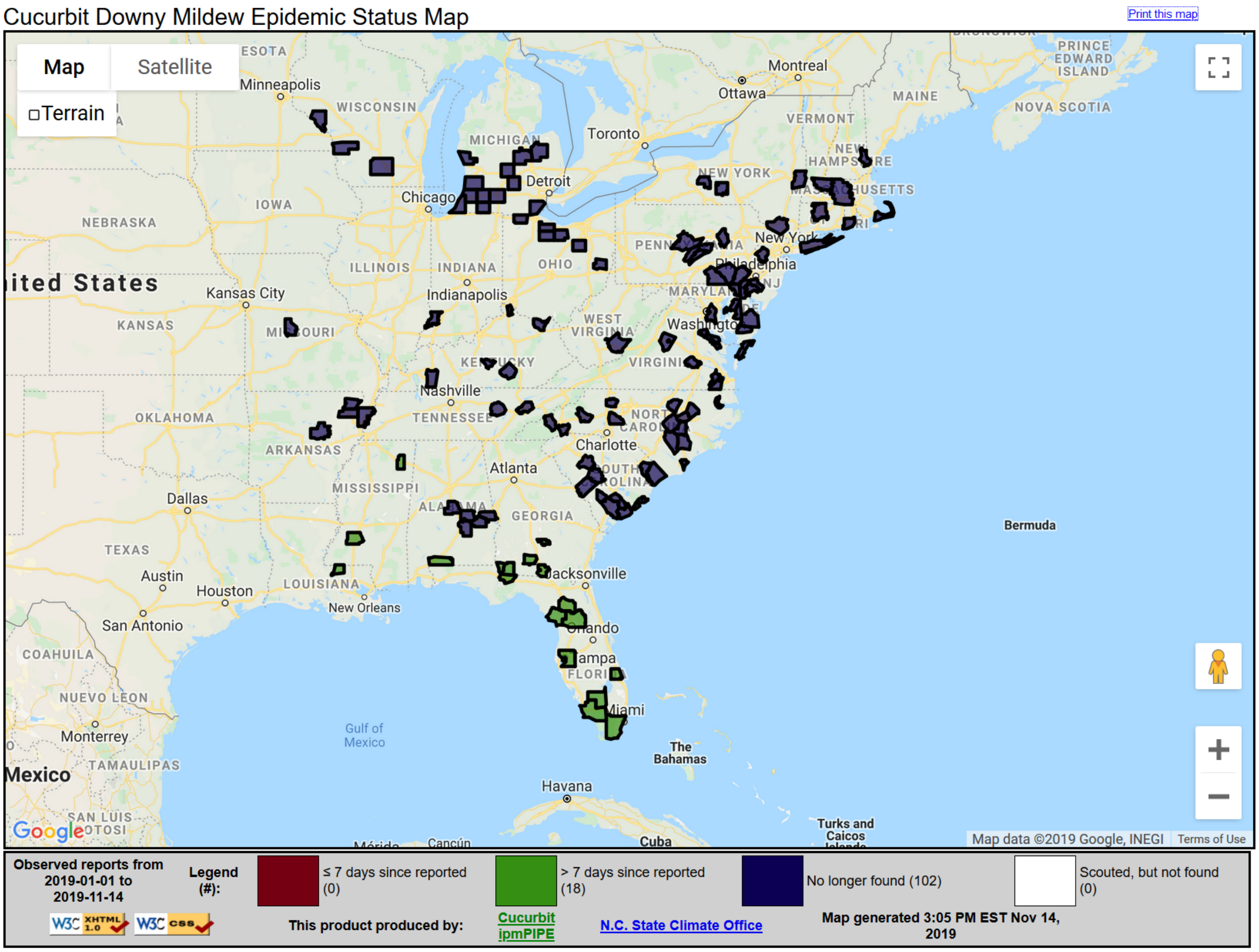
Routine testing of soil, crop, forage, and animal fecal samples is another essential part of documenting how well a farm is operating. Performing the same analyses repeatedly over time is an excellent strategy for detecting patterns and can serve as an early warning system for problems that may be developing but don't yet show visible symptoms. Soil properties tend to change slowly, so soil testing on an annual or semi-annual basis is particularly valuable. Doing so can help you to detect problems before they impact crops. Furthermore, in the early years of farming, annual tests provide important feedback on how management practices are affecting the farming system. You may be able to reduce the frequency of some tests once your farming systems stabilize.

For example, Jeff Main (Good Humus Produce) conducted annual soil tests on all of his fields. He noticed that the soil pH on the farm was gradually becoming more alkaline and wondered if the compost that he had been applying to his fields every year was the culprit. He submitted a compost sample to the lab for analysis and discovered that it had a high pH. Based on this knowledge, he changed his soil management practices by reducing application rates and finding a different compost supplier. Combined with diligent use of legume cover crops, these modifications reversed the trend in soil pH before he experienced significant yield declines and actually improved plant health and production. After many years of farming in this manner, his soil properties stabilized and he no longer needs annual soil tests.

BOX 4-2: The perils of confirmation bias and cherry-picking data.

Everyone is subject to biases. A common one is confirmation bias, which is the tendency to consider only new evidence that fits your pre-existing beliefs. Pay particularly close attention to how you interpret observations that fall outside of what you consider to be normal. It's all too easy to ignore them because they don't conform to your perspective on how things are supposed to be. Don't just cherry-pick the data that you like. Sometimes, that means you will acknowledge that mistakes were made or that you misunderstood the nature of the problem, but doing so can reveal new insights and lead to innovations.

FIGURE 4-2: ipmPIPE map of downy mildew from North Carolina State University Extension.

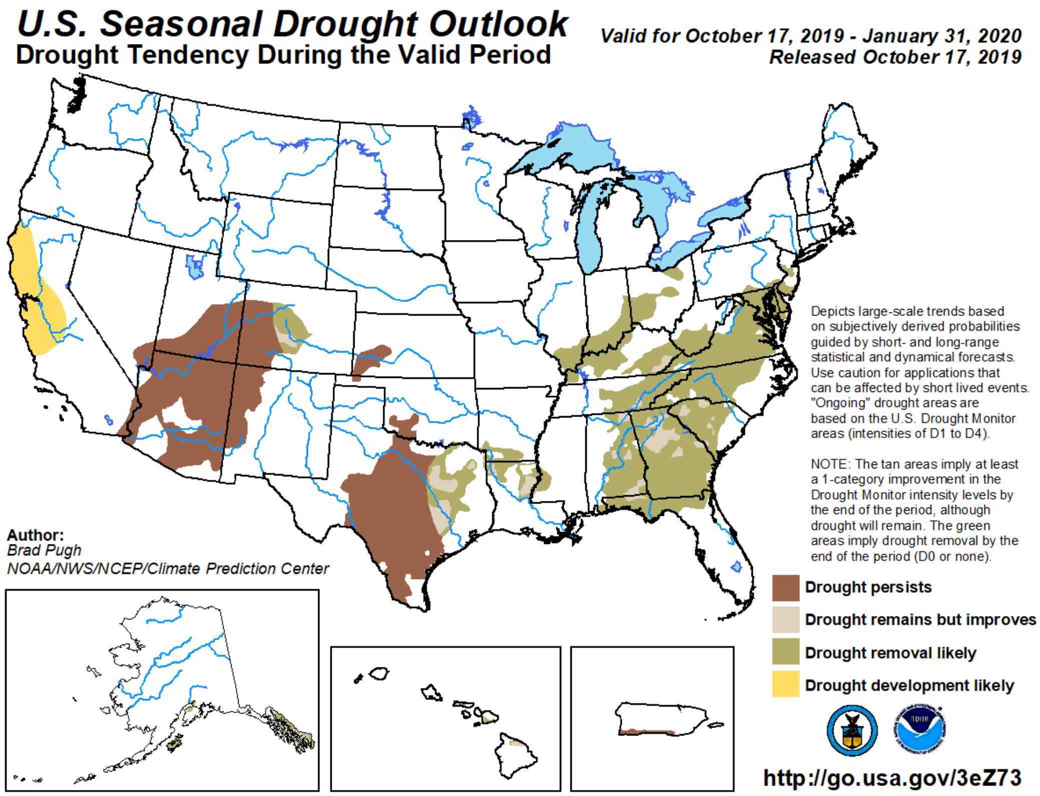


C-5 Collect outside observations

In addition to walking the farm, you can obtain information about environmental and economic patterns from outside sources, such as online data repositories. For instance, North Carolina State University Extension publishes locations of pest and disease outbreaks online (Figure 4-2). National and regional weather services can alert you to large-scale weather events like droughts and storms (Figure 4-3), while Weather Underground offers finely tuned forecasts based on data from the National Weather Service and a massive pool of personal weather stations, allowing users to select the station closest to their farm. Meanwhile, growing season predictions are available through Cornell University's Climate Smart Farming program (Figure 4-4).

In addition to providing raw data, these sources typically offer visualizations and analyses, as well. Lou Lego (Elderberry Pond Farm, Case Study #4) used National Oceanic and Atmospheric Administration climate data to verify his own anecdotal experience that precipitation was becoming more erratic and intense, which spurred him to research, evaluate, and implement a novel cultivation technique on his farm.

FIGURE 4-3: Drought prediction map from US National Oceanic and Atmospheric Administration.



C-6 Taste your own food

Although it may not be easily measured, one of the most important characteristics of food is its taste. The productivity and ecosystem health of the farm isn't very meaningful if consumers don't want to eat your food. Tasting the food coming from your farm ensures you are providing a high-quality product to customers. Plus, you may detect trends in taste before your customers notice them.

C-7 Invite feedback from customers

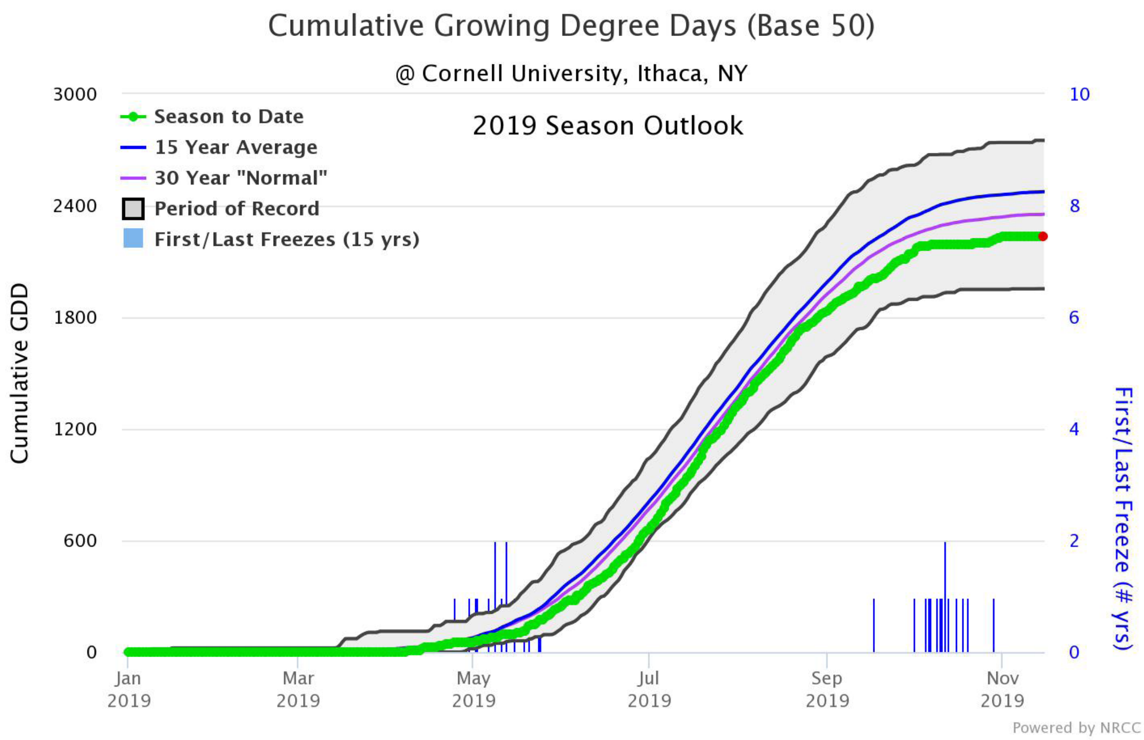
You can use many strategies to solicit feedback from customers, including asking them about their preferences at farmers' markets, mailing questionnaires to CSA members, or hosting taste-testing events. Quite a few farmers ask repeat customers what they liked or didn't like about the produce they bought in order to identify preferred cultivars. For example, Thor Oechsner (Oeschsner Farms, [Case Study #3]) offered bakers samples of flour from wheat varieties that he knew grew well on his farm and used this feedback to make final decisions about what varieties to grow, thus ensuring that the wheat he produced was well suited for the market he was planning to target.

C-8 Invite feedback from farm staff

Encouraging feedback from everyone working on the farm multiplies the number of "eyes on the fields" and is another valuable strategy for observing the farm system to identify problems. For instance, Lou Lego (Elderberry Pond Farm) realized that he could use sunflowers to draw pests away from his crops when a worker told him there were no cucumber beetles on the melons and squash planted near his sunflowers. He followed up this tip with a small-scale experiment in which he observed pest damage in crops surrounded by sunflowers to those without a flower border.

You can involve farm workers in their observation and data collection efforts in different ways. While some farmers actively solicit feedback during regular meetings, others simply ask questions if they suspect something is amiss or create a collegial environment that's conducive to sharing information.

FIGURE 4-4: Growing season predictions from Climate Smart Farming.



C-9 Assess equipment

Have a system to ensure your equipment is functioning on a year-round basis. Most of the farmers we interviewed reserved time annually (usually in the off-season) to inventory their equipment and carry out routine preventative maintenance. Evaluating the safety, functionality, and effectiveness of farm equipment ensures that farming operations can be executed in a timely fashion. A broken harvester isn't a big problem if there is a month to repair it, but it can be a costly issue if you don't notice it until a day before it's time to harvest your crops.

Equipment will also limit potential solutions. For example, Adam Squire (Unbound Glory Farm, Case Study #10) wanted to reduce erosion by shaping his beds to the contours of his farm, but this wasn't possible for him until he purchased a bed shaper attachment for his tractor.

If you can't find the right piece of equipment, you can develop your own innovative tool for the job; necessity is the mother of invention. After Steve Groff (Cedar Meadow Farm, Case Study #11) assessed the available cover crop termination equipment, he determined that no product really suited his needs. However, inspired by farmers in Brazil, he realized that he could use a rolling stalk chopper for a purpose completely different from its intended use: a roller-crimper in lieu of a mower.

Step D: Evaluate the farming system

While the tasks described in Step C are more or less done on a continual basis, the process of evaluation outlined in this section is typically carried out annually and serves as a starting point for planning the next growing season.

D-1 Review the annual farm schedule/calendar

Maintaining a calendar for scheduling is something common to nearly all farm operations. Any number of options—ranging from a wall calendar to detailed farm scheduling software—can help you remember what you did in past years and plan ahead for the future. In addition to outlining the timeline for farming operations, a farm schedule/calendar can help identify potential problems and opportunities for improvements. If you

TABLE 4-1: Comparison of cherry tomato enterprise budgets. Franzenburg uses a heated greenhouse while Johnson produces her cherry tomatoes in the field under an unheated, moveable high tunnel. Both farms had profitable cherry tomato crops, netting $1.31/lb at Franzenburg and $1.54/lb at Johnson. Used with permission; the full case study can be found on the Practical Farmers of Iowa website.

Cherry Tomato Enterprise Budget		
	Franzenburg	Johnson
Marketable harvest (lb)	941	1,200
Marketable harvest (pint)	1,255	1,600
Marketable harvest (lb/ft²)	0.87	1.71
Marketable harvest (pint/ft²)	1.16	2.29
GROSS REVENUE	$3,524.10	$3,160.00
Revenue/lb	$3.74	$2.63
Revenue/pint	$2.81	$1.98
Revenue/ ft²	$3.26	$4.51
Transplant supply costs	$12.70	$63.78
In-field supply costs	$202.95	$231.50
Marketing cost	$424.00	$38.70
Machinery cost	$0.00	$6.75
Building/structure cost	$236.63	$77.50
Land cost	$6.20	$3.20
Labor cost	$1,410.00	$887.90
TOTAL ANNUAL COST	$2,292.48	$1,309.33
Cost/lb	$2.44	$1.09
Cost/pint	$1.83	$0.82
Cost/ft²	$2.12	$1.87
Cost/revenue (efficiency)	0.65	0.41
NET INCOME	$1,231.62	$1,850.67
Income/lb	$1.31	$1.54
Income/pint	$0.98	$1.16
Income/ft²	$1.41	$2.64
Net/gross income (ratio)	0.35	0.59

have already settled on an issue to address in the coming growing season, a farm schedule will be essential to determine when you can address it.

D-2 Analyze financials

Like any small business, keep detailed records of your financials. You will already need to do this for tax purposes, and looking at multi-year trends provides an opportunity to adjust your business plan to make sure that you are on track. Tracking financials (such as sales records and expense reports) over time can help you identify potential financial problems, such as low rates of return, high costs, overleveraged debts, or depreciating assets. On the bright side, doing so might also uncover resources that you didn't know about. Specialized software (e.g., QuickBooks) can help guide you through this process.

Enterprise budgets are one of many financial tools that farmers can use to inform decision-making on the farm. They consist of four parts:

1. Estimate of total yields, prices, and income
2. Estimate of variable unit costs associated with producing something
3. Estimate of fixed costs for producing something
4. Record of net profit

A completed enterprise budget will determine the minimum prices needed to turn a profit. It will also identify the most profitable components of a farm operation and those that operate in the red. This will help you forecast how making changes in production, such as focusing on the most profitable enterprises or abandoning those that don't offer good returns on investment, will affect the profitability of your farm. Making a change is financially smart if the costs of the solution/innovation increase your farm's profitability, or at least decrease profits less than doing nothing.

We found an interesting example of how farmers use enterprise budgets to evaluate production systems in a Practical Farmers of Iowa research report (Table 4-1). Two farmers collaborated using enterprise budgets in order to compare and contrast the costs associated with differing cherry tomato production systems. One farmer (Franzenburg) grew tomatoes in a heated greenhouse, while the other (Johnson) used an unheated, moveable high tunnel. While Franzenburg bore substantially higher overall annual costs, she was able to sell her tomatoes at a higher price. Johnson had a shorter growing season but higher yields. The result of all of these tradeoffs and

TABLE 4-2: Yields recorded in variety trials conducted over four years. See the Practical Farmers of Iowa website for additional information on this example. Used with permission.

Mean Yield by Year				
Year	Variety	Crown weight (lb/crown)	Crown yield (lb/ft^2)	Yield with side shoots (lb/ft^2)
2014	Belstar	0.79	0.15	0.23
	Gypsy	0.86	0.17	0.34
2015	Belstar	0.92	0.22	0.22
	Gypsy	1.04	0.24	0.26
2016	Belstar	0.53	0.10	0.10
	Gypsy	0.61	0.10	0.10
2017	Belstar	0.91	0.19	0.21
	Gypsy	1.04	0.21	0.31

differences between the two production systems resulted in similar gross incomes, but the high tunnel system generated greater net income. This enterprise budget exercise identified inefficiencies in both production systems that could still be improved, such as increasing labor efficiency by planting varieties that were easier to harvest.

Enterprise budgets are not for everyone because they generally require farmers to focus on clearly distinct aspects of their farm operations, which may not work well in integrated farm systems. However, they can serve several functions in appropriate situations. These sorts of financial tools only consider economic value, overlooking many other values that you may have established along with your farm vision and mission. These data also only offer a snapshot in time (typically a year). Even though there's no question that it's critical for farms to be financially viable, it's not necessarily advisable to base your judgement entirely on financial analyses; that could lead to some decisions that maximize profits in the short term without concern for their long-term impacts.

D-3 Analyze records

We discussed the importance of keeping detailed records of farm observations. Analyzing these records can reveal concerning trends, identify problems before they grow, and find opportunities for innovative improvements. The more significant the issue you are investigating, the more essential it is to collect and analyze data rather than rely on memory. Although the farmers we spoke to used their memories and notes to inform day-to-day farm management, most also took time during the off-season to review their records and determine what they wanted to maintain, investigate further, or change during the next growing season.

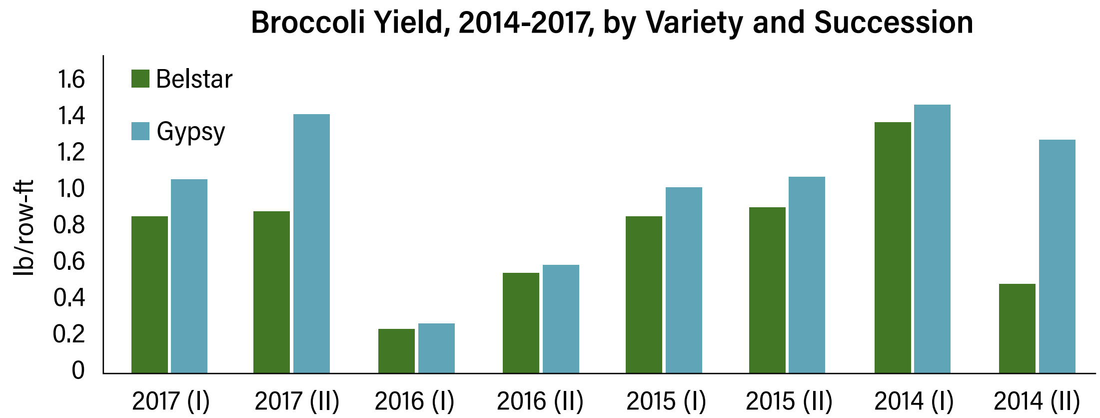
Your approach to analyzing records largely depends on the types of data you have recorded. The main point is to review your records from multiple years in order to gain a better understanding of how your farm is changing over time, due to either management decisions or factors out of your control (e.g., weather, new pests migrating into your area). Even doing something as simple as graphing yields over time can provide useful insights. Rob Faux, (Genuine Faux Farm) recorded yield data for two broccoli varieties using unreplicated, side-by-side trials. He found that yields were similar most of the time, but in three plantings, "Gypsy" had significantly higher yields compared to "Belstar" (Table 4-2 and Figure 4-5). Despite these higher yields in Gypsy, Rob plans to continue growing both varieties because yield is not his only criteria, and the Belstar variety has other characteristics he values. This reinforces how criteria for success can be varied and are defined, in part, by your farm vision.

D-4 Establish benchmarks

Benchmarking compares the relative performance of a farm business against a standard. Standards can include historical data from an individual farm, the performance of regional competitors, or industry-wide average standards. Successful benchmarking requires you to collect and record accurate data for your farm.

The main purpose of establishing benchmarks and indicators is to determine how your farm is changing over time. It can also be useful to have at least some

FIGURE 4-5: Bar graph of broccoli yields from two planting dates during 2014–2017. See Table 4-2 for more information regarding this example.



performance indicators (Box 4-3) that are comparable to other farms' benchmarks. That said, the interpretation of benchmarks may differ depending on the farm. For example, a farm located in an area with a weaker market and lower rent prices may generate less gross income compared to a farm in a more populated, high-income area, but the overhead costs of the former are likely to be lower as well, resulting in similar net profits. Comparing benchmarks across farms can be particularly useful in spotting areas where management changes can potentially improve performance.

The best benchmarks can be quantitative (e.g., yields, profits) or qualitative (e.g., taste, appearance) and will reflect your goals and the target markets. For example, Lou Lego (Elderberry Pond Farm) focuses on qualitative metrics (e.g., produce taste, attractiveness) because the majority the fruits and vegetables grown on his farm are used in the restaurant that is part of his farming operation. He noted that he might focus more on yields if he were supplying wholesalers. Thor Oechsner (Oeschsner Farms, Case Study #3) measures both wheat yields per acre and protein content. Thor needs to use a quantitative indicator of wheat grain quality because his customers, who are making bread, require flour made from high-protein wheat. Chaw Chang (Stick and Stone Farm) uses yield as a benchmark for vegetable crops he terminally harvests for storage. In contrast, he uses gross or net profit as the benchmark for crops that he can't store because increasing yields for these crops does not matter if he can't sell all of what he produces.

D-5 Review successes and failures

Review and reflect on past attempts at solving problems in order to understand how to build on and improve them in the future. Consider which past management changes effectively solved problems and which didn't. While the exact nature of the current problem will likely differ, you can still learn general principles from the previous problem-solving process. This requires you to adopt a "process-oriented mindset" in contrast to an "outcome-oriented mindset." Rather than bemoaning a failure, ask yourself: what challenges arose with carrying out the trial, and how could they be addressed? What aspects of my approach worked well that I would like to retain?

D-6 Review the farm production system

Reviewing your farm's means of production can allow you to identify problems or inefficiencies that waste resources in the long term and are prime candidates for more ambitious innovative improvements. Reducing waste is particularly beneficial because it can free up wasted resources (e.g., time, money, land, tools) for additional innovating and problem solving.

Reviewing farm production systems can be as simple as revisiting your business plan to take a critical view of your farm operations' current strengths and weaknesses. Questions to ask include:

- Which farm tasks do I particularly enjoy? Which do I not enjoy?
- Which farm operations are the most productive and offer the highest net profits? Which offer the least?

BOX 4-3: Suggestions for indicator selection.

Indicator selection is particularly important when it's difficult to measure something directly. Good indicators share a number of common characteristics:

- **Easy to monitor: Measuring indicators should be inexpensive and offer immediate information without delays.**
- **Stable: Certain indicators depend on external factors, making them highly variable and susceptible to change (e.g., price depends on market conditions). Choose indicators that are more stable and easily comparable.**
- **Appropriate in scale: For problems on individual farms, avoid focusing on either site-specific or landscape-level indicators.**
- **Concrete: Indicators do not necessarily need to be quantitative, but it's better for them to be easily understood, particularly with regard to whether a value is "good" or "bad."**
- **Relevant: Choose indicators that are indicative of the aspect of farm management you are concerned with. Be sure that the indicator is directly and causally linked (as opposed to merely correlated) with the process or characteristic you want to measure.**
- **Normalized: It's often a good idea to express indicators per unit area or volume to make sure they're comparable.**

The procedures for monitoring and recording indicator information are very similar to keeping records of farm observations. Keep the information in a single, centralized location for ease of use. Electronic spreadsheets and ledgers can assist with organization.

- Are there unnecessary inputs that I could do without or waste I could reuse or recycle within my system?

One book mentioned by several farmers is *The Lean Farm* by Ben Hartman. Lean farming applies concepts developed by Taiichi Ohno, a Japanese industrial engineer and father of the Toyota Production System, which became generally known as lean manufacturing. Applying these concepts to farming systems provides a systematic way to identify and reduce inefficiencies. The first step of this process is to use market research to identify customer values, which drive both farm production and marketing. Once you identify what customers value, you determine how to produce that value. This involves taking a systems perspective of your whole farm operation and determining the steps and resources needed to produce a particular product that customers appreciate. The supply chain analyses described on page 24 are particularly useful to inform this task. Lean farming principles—like nearly all the concepts in this manual—are continuous and cyclical.

D-7 Identify important trends/changes

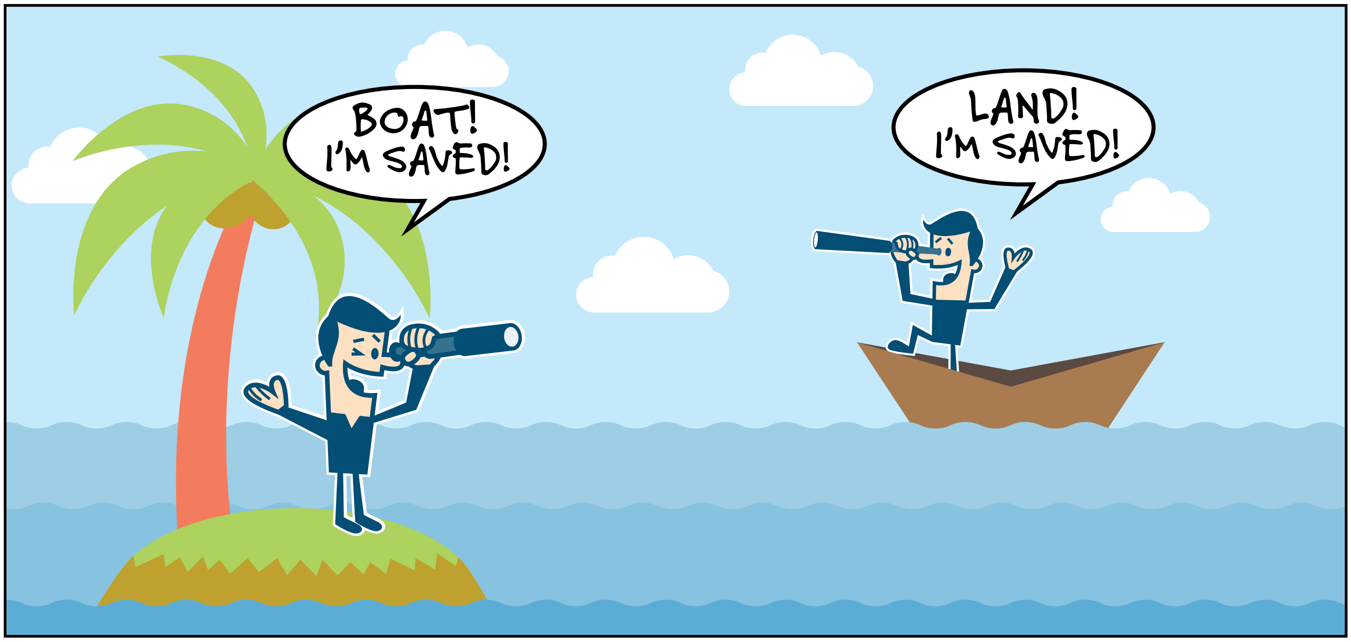
Change is the only certainty in life. New regulations affect what you can do on your farm, shifts in consumer preferences impact demand for farm products, and the ranges of introduced pests can expand or contract. The challenge is discerning "important" changes from the background noise of normal variability.

Three main factors interact to determine whether or not a trend is important. The first two considerations are the speed and the scale of the change; the faster and more pronounced it is, the more important it will be to address. Finally, the nature of the change is also relevant. What is important depends on your unique perspective on the situation (Figure 4-6). For instance, when a local factory converted to biofuel-fed heat generators, local dairies using loose housing systems suddenly had to reckon with higher prices for the wood chips they used for their compost bedded pack barns. They ultimately had to choose between paying higher prices, changing their bedding material, or converting to a stall barn. Meanwhile, nearby vegetable growers were not particularly affected by this change.

D-8 Consult experts

There are many points in this process when it is useful to seek information from outside sources. Consulting with experts can accelerate the information-gathering process. Specifically, seeking advice from experienced farmers and industry experts can serve as an excellent

FIGURE 4-6: What is "important" depends on perspective.



starting point for finding a solution you want to try, and can save you time and effort.

Klaas Martens (Lakeview Organic Grain) sought advice from university scientists to get help diagnosing the cause of his declining bean yields. The scientists identified the root pathogen that was causing yield losses, allowing Klaas to rule out soil problems, such as chemical imbalances or compaction, and to focus on finding ways to reduce pathogen populations in his fields. Lucy Garrison (Stick and Stone Farm) regularly emails seed dealers to learn more about the lineage and characteristics of hybrid cultivars. She uses this information to select the most interesting varieties to include in the annual variety trials she and Chaw Chang conduct every growing season.

D-9 Prioritize problems/opportunities

Farmers often remark there are never enough hours in the day to accomplish everything that needs to be done on a farm. As a result, it isn't surprising that farmers prioritize certain problems over others. Prioritization depends on a number of factors including these considerations:

- **Extent of the problem:** Prioritize problems that affect the entire farming operation above those that might only impact one crop or a single field.
- **The magnitude and nature of the negative consequences:** Attend to problems with significant consequences for your bottom line immediately.
- **Incremental problems with longer timeframes:** Don't ignore these until they become urgent. For example, negative trends in soil properties often occur over many years and will only worsen without taking steps to correct your soil management system before yields are impacted.

TABLE 4-3: Eisenhower matrix for task prioritization.

	Urgent	Not Urgent
Important	Do	Plan
Unimportant	Delegate	Ignore

An Eisenhower matrix (Table 4-3) is one of many tools that can help you prioritize what needs to be done. This approach classifies problems and tasks depending on their urgency and importance. In general, address urgent and important tasks as quickly as possible. Develop a plan to address important, but non-urgent

tasks in a way that prevents future problems. Delegate unimportant, urgent tasks; unimportant, non-urgent tasks can largely be ignored.

Problem solving tends to be more urgent than innovation, but that does not mean it's necessary to prioritize the former over the latter, or even that they're mutually exclusive. Innovation can result in substantial improvements in your farming system and address a suite of small, related problems with one sweeping change. Time-sensitive problems can be minor to the overall farming operation and have limited impact on the farm system as a whole. The challenge is to balance the time devoted to improving your farming operation so that you react to important problems as they arise while also reserving time for proactive innovations.

Recommended resources

Benchmarking

- Franks, J. R., & Collis, J. (n.d.). On-farm Benchmarking: How to do it and how to do it better. School of Agriculture, Food and Rural Development of Newcastle.
- Hudson, T., & Krause, M. (2014). How can benchmarking assist in the management of your business? (No. AES000006). Australia: Grains Research & Development Corporation.
- Kahan, D. (2013). Farm Business Analysis: Using benchmarking (Farm management extension guide). Rome: Food and Agriculture Organization.
- Parsons, J., Tranel, J., & Hewlett, J. (n.d.). Benchmarking in agriculture (No. RMP-201412.001). United States Department of Agriculture RightRisk.

Collecting outside observations

- ATTRA | National Sustainable Agriculture Information Service. In: ATTRA | National Sustainable Agriculture Information Service. Accessed 13 Mar 2019c
- Climate Smart Farming Powerful and user-friendly climate tools for farmers in the Northeast. Accessed 13 Mar 2019f
- Data Snapshots Start Page | NOAA Climate.gov. Accessed 13 Mar 2019d
- eOrganic. Accessed 13 Mar 2019e
- Go Botany. Accessed 13 Mar 2019f
- IPM PIPE. Accessed 13 Mar 2019a
- Practical Farmers of Iowa. Accessed 13 Mar 2019d
- PubAg. Accessed 13 Mar 2019a
- Rodale Institute - Pioneers of Organic Agriculture Research. In: Rodale Institute. Accessed 13 Mar 2019b
- USA National Phenology Network | USA National Phenology Network. Accessed 13 Mar 2019c
- Weather Forecast & Reports - Long Range & Local | Weather Underground. Accessed 13 Mar 2019b

5 Problem solving and experimentation

In this chapter, we discuss how to develop, test, and evaluate solutions. Steps E-G are the core of on-farm experimentation and closely mirror the adaptive management cycle presented in Chapter 2. You can repeat the steps presented in this chapter over multiple growing seasons or within a single season to fine-tune and improve promising solutions and innovations.

Step E: Design actions

E-1 Investigate the issue

Rather than developing completely novel solutions, draw on previous education and experience combined with information obtained from a variety of sources. In addition to extension, library, and internet resources (Box 5-1), observing other farms can inspire innovative solutions.

If you are reacting to an existing problem, determine *why* and *how* it's occurring before jumping to solutions. In addition to allowing the diagnosis of the true cause(s) of the problem, this initial analysis can help identify potential ways to solve it using ecological processes and on-site resources. Klaas Martens (Lakeview Organic Grain) urges farmers to "think about the unacknowledged assumptions you're making and do research to confirm that they are correct." Otherwise, you may mistakenly reach the wrong conclusion about a symptom and overlook the problem's fundamental cause, leading you down the wrong path.

Diagnosing plant or soil health problems can be particularly tricky. Lou Lego's problem (Elderberry Pond Farm) with cucumber and downy mildew is a great example of the value of reaching out to confirm the correct diagnosis of a problem. Lou noticed that his cucumbers' response to downy mildew changed from a minor nuisance that reduced yields to a devastating disease that quickly killed the plants. Changes in the way plants respond to a pathogen can have many causes, including

BOX 5-1: An inexhaustive list of online resources for on-farm problem solving.

- **ATTRA Sustainable Agriculture: Information regarding current events in farming.**
- **Climate Smart Farming: Information on improving farm resilience to climate change impacts and limiting greenhouse gas contributions.**
- **eOrganic: An online network of organic farmers offering articles, webinars, and forums for information exchange.**
- **Go Botany: A user-friendly method of identifying weeds.**
- **IpmPIPE: A pest information platform showing maps of pests reported in the continental United States.**
- **National Oceanic and Atmospheric Administration: Weather forecasts and historical climate data.**
- **Network for Environment and Weather Applications: Network of observations regarding weather and pests.**
- **Practical Farmers of Iowa: An organization focused on promoting farmer-led research that offers research reports, protocols, and webinars.**
- **PubAg: Database of US Department of Agriculture publications.**
- **Rodale Institute: Organic farming research institute offering farmer training, webinars, and online courses.**
- **Weather Underground: Localized weather forecasts.**

poor nutrition or other soil-related problems, infection with a second pathogen, or the development of a new, more virulent pathogen strain. Lou sought advice from North Carolina State Extension and learned that a deadly new strain of downy mildew had originated in the south and was spreading north. With that information, he could then develop an effective solution based on his knowledge of the actual problem (Case Study #6).

If you are considering substantial modifications that fundamentally change your management, devote more effort to information gathering. Start with the information you used to help prioritize farming issues, and add to it by following up with peer networks and experts. While investigating the science behind the issue by consulting with researchers or reading the scientific literature it may require extra effort, it may pay off in a big way. This is particularly true in cases where using established solutions may not fit well with your situation. Moreover, innovation requires thinking outside of the box and having as much information as possible about the big picture.

Peer-reviewed journal articles found through databases like Google Scholar and university libraries are generally the most reliable sources of information. However, journal articles aren't particularly accessible to farmers; the writing is often technical and can be full of jargon, and there is usually an access fee. You can request journal articles from extensionists and university-associated scientists at no cost. Some land grant libraries also allow non-affiliated community residents to use library resources for a small annual fee.

Secondary sources (e.g., extension materials, grant reports, trade publications, books) produced by recognized institutions, such as government agencies and university extensions, often boil down the information in these primary sources into accessible language. They will typically list the primary literature they used so you can find it if you need further information. However, secondary sources such as industry or trade publications start with their own assumptions and can be biased towards or against particular practices. Pay attention to who is providing the information to ensure that the authors are qualified while also being aware of their potential biases.

E-2 Research solutions/options

Once you understand the nature of the problem and feel you have sufficient background knowledge about the subject, you are ready to consider solutions. You will likely run into examples of solutions while investigating a problem, but it can be important to dig a little deeper before deciding how to move forward depending on the

BOX 5-2: Evaluating vendor claims.

It seems that there is now a quick fix or silver bullet you can buy to solve any problem that may arise on your farm. These include soil microbial additive products (i.e., so-called bug-in-a-jug), brix enhancement, and cation balancing, among others. However, many of these popular products and practices don't have much independent testing to back them up. Here are a few tips for evaluating sales pitches:

- **Don't be afraid to ask for data or experimental results associated with the product or process. Extension educators can help you find any published results.**
- **Correlation does not always mean causation. Just because an effect was observed after a particular change doesn't mean that the change was what caused it. There needs to be a link that explains why one led to the other.**
- **Be wary of claims backed only by the dealers' own testing, which may bias results.**
- **Was the testing rigorous and appropriate? The principles we outline in Chapters 5 and 6 (e.g., importance of controls, accounting for variability) apply to testing products, too.**
- **Consider the risks and rewards of a product. The more involved and expensive solutions are, the warier you should be of applying them.**
- **Extraordinary claims require extraordinary evidence.**
- **Is the solution coming from an established/reputable institution?**
- **Be aware of your personal biases. Easy solutions are appealing to busy people, and it's easier to accept ideas that are in line with your perspectives.**

Talking with other farmers to hear about their experiences may be a good way to separate the wheat from the chaff. Still, be sure to do small-scale testing on your own farm to see whether a solution is as good as it claims to be.

scope of the change you are considering (Box 5-2). Furthermore, evaluating more than one solution is especially important in cases that require you to make significant modifications. In addition to collecting information to assess how well different options may work in practice, consider whether they're compatible with your broader goals and farming practices. Extensionists and other farmers can help identify pros and cons of potential solutions, especially if they have personal experience with them.

E-3 Assess risks and rewards

Methodically evaluating the risks/rewards associated with each potential solution is the most effective way to lay the groundwork for choosing which option to try on your farm. The effort put into this process needs to correlate with the size of the anticipated modification. You can use a mental risk/reward analysis for evaluating small changes, but projects requiring extensive resources (e.g., time, money, labor) need a more thorough analysis. This assessment can be as simple as writing down pros and cons revealed through your initial research or can include a more complete analysis of anticipated resource needs (e.g., amount and timing of labor needs, costs), potential impacts on income, vulnerability/resilience to climate change, domino effects on other farming operations/crops, and input from stakeholders/customers. Having a clear idea of what you want to accomplish (e.g., income or yield goals, reduced labor) will determine what you include in the risks/rewards analysis and how thorough it needs to be. We discuss this further in the Identify Success Criteria section.

While some costs and benefits can be quantified (e.g., the amount of time or money needed to implement a solution, returns on investment), others are intangible (e.g., a solution's effect on quality of life, how enjoyable a task is). Both are important to consider. Even though it may be more straightforward to use objective, quantitative metrics, evaluating risks and rewards is largely a subjective process that reflects your personal goals and values.

E-4 Choose the best course of action

Once you have determined the costs and benefits of potential solutions, choose the best of those available depending on their effectiveness, profitability, and alignment with your farm goals. In some cases, you may want to compare more than one approach, or, if they are not mutually exclusive, determine if two complementary strategies can be implemented together. Increasing the number of potential solutions you evaluate can complicate the experimental design, but there are ways to minimize this tendency (examples are provided in Chapter 6).

The criteria used by farmers at this stage are as varied as their farming systems and personalities. For instance, to decide whether to test a possible solution, Klaas Martens (Lakeview Organic Grain) weighs the difficulty and expense of implementation. He sets a low bar for testing options that are easy or cheap because, "the worst I'll do is learn something that isn't necessarily useful." He is much more careful when it comes to trying out approaches that are resource-, time-, and effort-intensive. In those cases, he requires more evidence demonstrating a high likelihood of success. Karma Glos (Kingbird Farms) agreed with Klaas's approach, but before starting big projects, she also performs an analysis of projected income. One of her key criteria is that the solution needs to pay for itself within ten years for her to pursue it further.

Our initial reactions to a new problem rarely result in the best solution. When Lou Lego (Elderberry Pond Farm, Case Study #6) faced the problem of downy mildew killing his cucumber plants, he initially thought that he would simply stop growing cucumbers and replace them with another crop. However, when Merby Lego, his co-farm manager and wife, pointed out the importance of cucumbers for their restaurant, he realized he needed to come up with a solution that would allow him to grow cucumbers. Discussing a potential solution with Merby, who is more involved in the restaurant, provided a broader, well-rounded perspective and led to a more suitable solution.

E-5 Design a trial

Developing an effective plan for testing solutions and innovations can be a complex task. There is no experimental design that will work in all situations; however, following the key principles will help you to design experiments that are practical and produce useful results. These principles bring together the most valuable aspects of formal and informal research methods and reflect years of farmers' experience. You can find examples of experimental designs that illustrate application of these guidelines in Chapter 6.

Integrate experiments with farming activities

The extent to which you can integrate experimentation with your normal farming activities will have a huge impact on your willingness and ability to actually carry out experiments. Some steps that will simplify things are:

- Arrange experimental plots so they are compatible with field/bed layout and equipment dimensions. Practical Farmers of Iowa recommends using plots with field operations in mind. For example, use plot sizes that are the same width as your equipment or are multiples of that width, and arrange plots so they do not interfere with the normal movement of equipment though fields.
- Locate experiments with accessibility in mind. You will be more likely to keep an eye on trials that are convenient to visit.
- As much as possible, rely on data you are already collecting as a part of normal farm operations (i.e., yields). If you do need additional data, try to focus on variables that are simple and quick to measure.
- Schedule research activities that are beyond the scope of normal farming activities into periods that are otherwise less busy.
- Make experimentation a group effort by involving co-managers and delegating responsibilities to other farm staff. For example, Chaw Chang (Stick and Stone Farm) plants the variety trials they conduct on their farm, but his co-manager/wife researches and identifies new varieties to evaluate along with preparing the annual seed order.
- Keep experiments small at first before scaling up. This can prevent wasting a lot of time, energy, and money on solutions that aren't effective.

Match the experimental design to your core question

Ultimately, any experiment worth doing needs to address your core question, while also being feasible to carry out alongside normal farming activities. While simple experiments are easy to implement for yourself, it can be worthwhile to use a more formalized experimental design that draws from the scientific method in situations where changes are significant, costly, or difficult to measure. This might involve testing multiple solutions at the same time in multiple plots. In contrast,

you can use a simpler experimental design when the change is minor, inexpensive, or if you expect clear or consistent outcomes (i.e., crop dies, yield loss).

As an example, Jill Beebout (Blue Gate Farm), Alice McGary (Mustard Seed Community Farm), Rob Faux (Genuine Faux Farm), and Sarah Foltz Jordan (Keepsake Farm) tested single small strips of various annual flower mixes to attract pollinators. They did not use complex experimental designs because they all wanted to add pollinator habitat on their farms and were trying to find one mix that would work well; this issue did not necessarily threaten the viability of their farms. On the other hand, Jack Boyer (Jack Boyer Farms, Inc.) and Tim Sieren (Green Iron Farms) used a replicated randomized complete block design (see Chapter 6 for further details on this experimental design) to evaluate a new cover cropping system's effect on weed abundance and cereal crop yields. This was a drastic change and would substantially impact the profitability of their farms, so they wanted to use a formal scientific experimental design. In addition, evaluating weeds can be challenging because their distribution tends to be highly variable across fields, further necessitating a rigorous experiment design in order to yield meaningful results.

Another important consideration is the duration of the test. You can sometimes evaluate small modifications in a single growing season. However, due to interactions with seasonal weather variations, it's usually a good idea to plan to test new practices for several growing seasons before concluding whether or not they've made a positive impact. Jean Paul Courtens (Roxbury Farm) likes to obtain up to three years of data for big changes on his farm to make sure the failure or success he observes at first is not just a fluke. He does, however, slightly vary the experimental treatment each year to see whether he can improve the outcome. In the case of integrating bell beans into his cover crop rotation (Case Study #2), Jean Paul tinkered with the percentage of oats and bell beans in his seed mix to achieve benefits in both weed suppression and soil nutrient enhancement.

Consider how different sources of variability could influence the results

Without question, the solutions you consider and the practical issues involved in testing them on a working farm play a big role in determining the best experimental design. It is also almost certain that you will overlook something in the design or that the experiment will differ from the original plan. However, it is useful to try and anticipate factors that might impact your experiment to avoid implementing a flawed design. Doing this will help you work with, rather than against, circumstances out of your control. The three main sources of variation that affect results in field trials, regardless of where they're conducted, are:

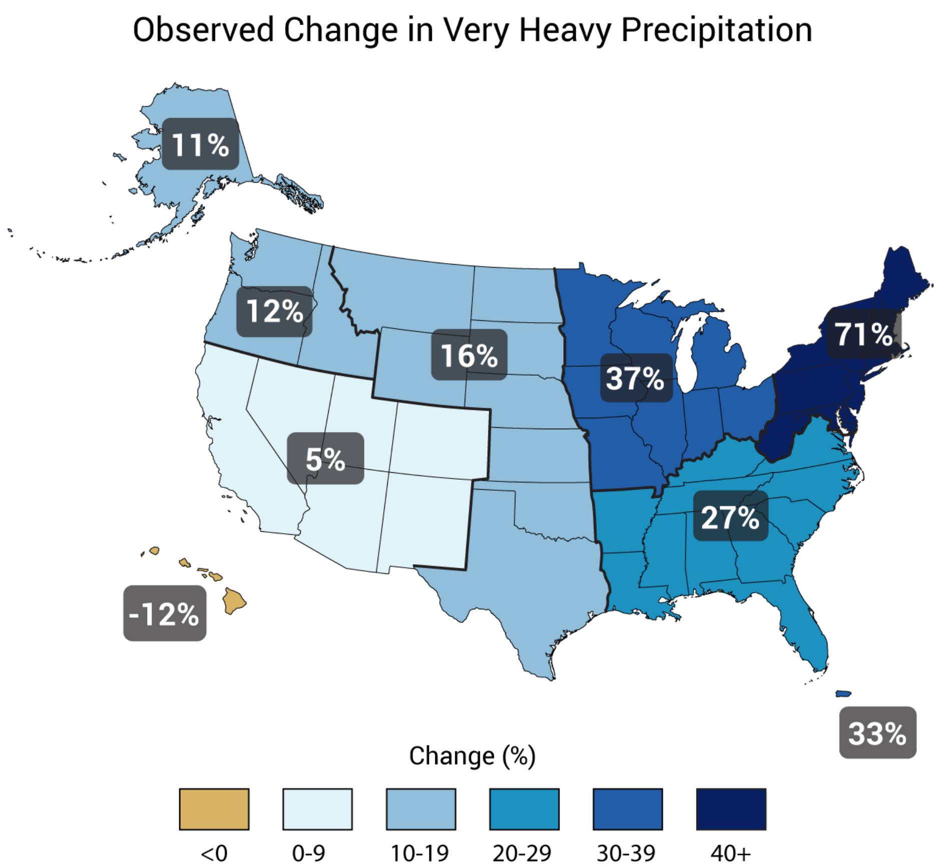
1) climatic inconsistency,
2) different environmental conditions across and within fields, and
3) differences in how people perform the work associated with experiments.

The effects of climate change are numerous and vary by location. It is extending the growing season in much of the Northeastern United States, as is readily apparent in flowering times and migration patterns. Weather patterns have also become more and more inconsistent and extreme in many regions of the United States, making it difficult to plan accordingly. For example, from 1931 through 1996, the amount of precipitation falling during weeklong, once-a-year precipitation events increased significantly across the country. In the Northeast, the amount of precipitation falling in the heaviest storm events has increased by 71% over the past five decades (Figure 5-1).

In addition, many environmental variables vary between and within fields. It's important to consider these differences when choosing where to test modifications. In some cases, you may intentionally choose a field that has been giving you problems (e.g., poor drainage or low fertility) in order to improve it. On the other hand, for testing a more general improvement, you may want to know if it will achieve your goals regardless of variability in local conditions. In this case, you will likely want to try out the practice in a couple of fields that represent the full range of settings where it could be implemented on your farm. Lastly, use your knowledge of within-field variation to avoid locating your trial in an abnormal section of the field or a set of problem beds. Regardless of the particular improvement you are testing, factor environmental variation in soils, the surroundings, water, and any number of other factors into your experimental design.

Finally, differences in who performs certain tasks or the techniques they use can introduce an unexpected source of error and affect results. For instance, the effectiveness of field operations such as tine weeding or cultivation often reflect differences in operator skill level. Having the same person manage the whole experiment

FIGURE 5-1: **Percent increases in the amount of daily precipitation falling during the heaviest 1% of storms from 1958 to 2012. Trends toward more intense precipitation are particularly strong in the Midwestern and Northeastern US. Copied from U.S. Global Change Research Program.**



minimizes this source of variation. If you are involving multiple people in the work, each person can rotate responsibilities so the differences you observe between potential solutions are a result of the change in management, not the person performing it. Alternatively, each person could manage a different section of each experimental plot so that no single person is managing a single plot by themselves.

Is a control plot necessary?

To decide whether the modification you are testing is actually an improvement, compare outcomes to some type of benchmark, typically one that reflects your usual practices. The chosen benchmarks will vary depending on the question being addressed. Benchmarks can also differ from "control" treatments used in formal agricultural research conducted by universities. A "control" or "check" is identical to the "treatment" in all aspects other than the practice to be tested. To illustrate this, consider Tom and Irene Frantzen's (Frantzen Farm) experiment testing whether apple cider vinegar supplementation could improve pig health, as measured by vitality, growth, and coat quality. One group of pigs received apple cider vinegar in their feed (treatment group) while another did not (control group).

> A "control" or "check" is identical to the "treatment" in all aspects other than the practice to be tested.

The simplest benchmark used in on-farm experimentation is comparing the present (new modification) with past outcomes resulting from normal practices. This can be very effective for testing some improvements if you have reliable data averaged over multiple seasons to

compare with the outcomes of your trial. However, there are drawbacks to this approach that can lead you to misinterpret results. The most problematic aspect of this approach is its vulnerability to seasonal variation. If the weather is unusual during your experiment, observed differences in the outcomes of your trial could be due to differences in the weather during the trial and the weather during the previous growing seasons you are using as your benchmark. Conducting multiple repetitions of the trial for several seasons can provide information on how the solution interacts with weather, provided you carry out the experiment in fields with similar environmental conditions (e.g., soil type, drainage) and minimize year-to-year variation in the management practices that you aren't testing (e.g., irrigation, planting, harvesting). These requirements can be tricky to carry out, and as a result, it's often worthwhile to use a side-by-side comparison of the modification versus your normal practice.

Side-by-side comparisons of the normal practice (control or check) and the improvement (treatment or experimental plot) are very doable, and farmers commonly use this design. In fact, it's the single most important aspect of formal experimental design that is both valuable and practical for farmers to implement. Choose experimental and control sites that have similar environmental conditions in order to reap the full benefits of this design. The best approach is to situate control and test plots next to one another in an area that is relatively uniform. Using two fields and managing one of them with your normal practice while implementing the modification in the other field does not provide a reliable control and is susceptible to producing misleading results.

It's simply impossible to avoid having some differences between fields on a working farm. Even when soil type, drainage, and topography are identical between fields, legacy effects of management history have potent impacts on growing conditions. For instance, the legacy effects of one-time differences in soil amendments can linger for several years. In addition, even in fields with identical crop rotations and management, large differences in growing conditions between fields are still common. Furthermore, the crop that was grown the previous season can have an enormous impact on field conditions in the following field season. Recent cropping history has a particularly strong effect on disease and weed pressure conditions.

When is replication necessary or particularly advantageous?

Perhaps one of the most significant differences between farmer experimentation as part of adaptive management and academic research is the use of replication (Box 5-3). Farmers have succeeded in making an enormous number of improvements and innovations without replicating treatments in the same field or across fields during the same growing season. Instead, farmers tend to replicate trials over time by repeating trials across multiple seasons. This underscores the importance of talking with more experienced farmers who have been farming for a while and know whether the conditions in which you experimented are normal and representative. It may be easier to accomplish this in family farms with long lineages of information about a particular site that has been passed from generation to generation.

We discuss the pros and cons of replication in Chapter 6 along with specific examples of different experimental designs. The main advantages of using a replicated design is that it allows you to account for potential sources of variability in the experiment and test multiple solutions to find which works best in various settings in a single growing season. Then, if the outcome is favorable, you can continue to evaluate or begin to implement the practice in subsequent growing seasons to learn about its resilience to varying weather conditions.

The main drawback of a replicated design is that it requires more time and resources. A simple model of a replicated experiment commonly used on farms is paired

BOX 5-3: The importance (or lack thereof) of replication.

Replicated treatments are a critical part of the scientific method used in formal agricultural research. Replication increases the ability of researchers to distinguish between treatment effects and other sources of variability, such as soil variation across and within fields and unintentional management-induced variation. In formal research, a minimum of three replicates are necessary to conduct statistical analysis of the data. Replicated experimental designs can speed up the research process by allowing researchers to quantify the effects of different treatments while accounting for natural variability within a single growing season.

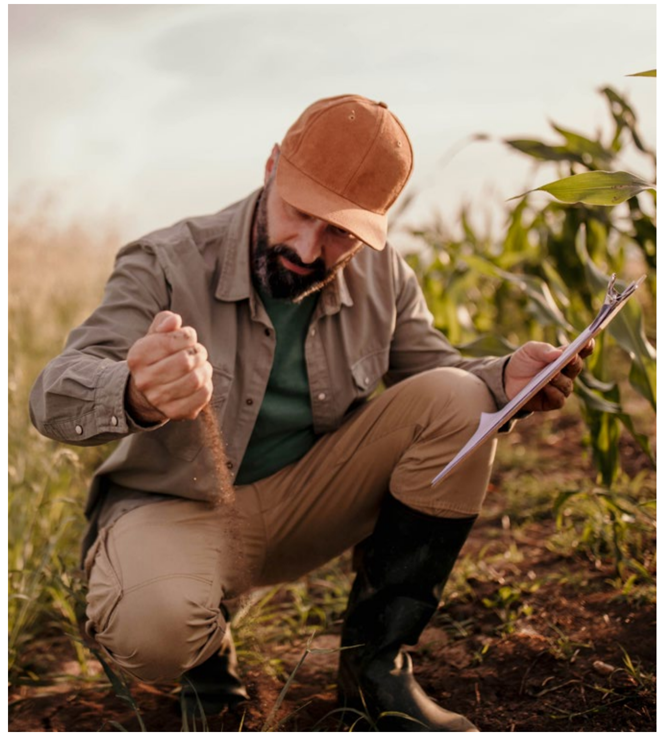
trials. Farmers either establish multiple side-by-side control-treatment pairs across a single field to control for variation in environmental variables (e.g., soil conditions or weed pressure) within fields or establish paired control-treatment plots in several separate fields to control for differences in growing conditions across the farm. If you are considering an experimental design that involves multiple treatments and replication, we strongly recommend that you read Chapter 6 and consider finding an extension collaborator to assist with design and monitoring.

In general, we don't recommend farmers use more advanced experimental designs (e.g., replicated, randomized, complete block designs) because they tend to over-complicate management and data analysis in most situations. However, replication may be important if a solution is costly to implement, or if the outcomes are particularly sensitive to environmental variation. Collaborating with several other farmers can help to provide some degree of replication. For instance, Andy and Melissa Dunham (Grinnell Heritage Farm), Mark Quee (Scattergood Farm), and Jorden Scheibel (Middle Way Farm) all coordinated to evaluate the impact of paper and plastic mulch on weed populations, as well as crop yields. Each farm established one set of side-by-side plots comparing the two mulching systems to a control (i.e., bare soil). This reduced the amount of land each needed to devote to the experiment, which was particularly valuable for them as small farmers who needed to maximize the productive capacity of their acreage. However, it also allowed them to account for variable environmental conditions and enabled later statistical analysis.

Anticipate problems that might come up during the trial and consider how to respond

Unexpected events beyond your control can end up jeopardizing any field experiment. The majority of these are weather-related circumstances that farmers deal with on a regular basis. You probably can't salvage either the crop or an experiment following extreme weather that floods the field and causes severe crop damage. However, there are instances where you can respond to unexpected events and maintain an experiment. For instance, although a surprisingly dry spring can pose some threat to plant survival, this can be addressed by irrigation, as long as you irrigate in the same way for all treatments.

Furthermore, unexpected events can open new doors and present opportunities to study options you hadn't



considered before. Thinking about potential challenges or things that could go wrong can increase your success in using experimentation as a tool to improve your farming system, but only if you follow up your concerns with steps you can actually take to respond to these pitfalls. Running through possible scenarios beforehand can make the difference between letting circumstances beyond your control disrupt the trial and benefiting from chance events. Examples of how experienced farmer-innovators dealt with and took advantage of unexpected events during their trials are included in the case studies presented in Chapter 7.

E-6 Identify success criteria

To ensure that you will learn something from your trial, it's best to decide how to evaluate outcomes during the design process. Collecting and keeping track of measurements and observations is one of the most challenging aspects of experimentation. Choose variables and measurements that reflect the experimental goal while being compatible with both your experimental design and normal farming activities.

Experienced farmers use both qualitative and quantitative observations, each of which have their own pros and

cons. Quantitative methods involve numerical measurements (e.g., precipitation per day, yield per acre, or soil nitrogen content). Collecting your own quantitative data requires you to devote time to carrying out, recording, and organizing measurements. On the other hand, these data can be less prone to personal bias than qualitative data based on observation, and they can help to detect obscure treatment effects that may remain undetectable through observation alone.

Qualitative data include any information relevant to your research goal, even simply observing the growing conditions of the experiment and estimating crop performance by visual assessment. Qualitative data are typically easier to integrate into normal farming activities, but the methods involved can be subjective and introduce observer bias. That said, qualitative data that are collected systematically in a way that attempts to control personal biases can be very effective for documenting outcomes and providing a basis for solid conclusions.

There is nothing preventing you from using both types of data to gain a more complete, well-rounded perspective on experimental results. Both types can be useful for evaluating experimental outcomes. Bruce and Connie Carney (Carney Family Farms) and Dave and Meg Schmidt (Troublesome Creek Cattle Co.) measured the fatty acid composition and quality (taste, texture, etc.) of the meat from their grass-fed cattle to determine the optimal harvest window. Using a number of qualitative and quantitative metrics helped them consider the range of possible outcomes of different harvest times, all of which are relevant to consumer preference and the performance of their farm operations; just measuring yield wouldn't matter if the product was of low quality and no one wanted to buy it.

The specifics of what you will document during your test depend on your research goal and experimental design, but there are three basic categories of information necessary to interpret results:

1. **Management practices:** Documentation of how you planted and managed the plots, including data such as seeding rates, crop variety, soil amendments, timing of field operations, and equipment used.
2. **Weather data:** At a minimum, you need basic information on temperature and precipitation. It can be particularly useful to note any extremes occurring during the experiment. Installing a personal weather station can automate this process and save time in the long run (Appendix IV).
3. **Primary results:** These are criteria for success that you will use to evaluate whether the change in farming practice will be beneficial. The variables you measure need to address the question of interest. Some examples include crop yield and quality, net income, labor, and quality of life.

Few farmers have the time to collect quantitative measurements beyond those normally used in financial records (e.g., income) or for certifications (e.g., organic certification). Besides these data—which usually include soil tests, timing of field operations (often recorded on a calendar, field notebook, or journal), yields, farm expenses, and sales—systematic observation is the most common approach used to monitor results. It may be more practical to use qualitative observations of growing conditions to interpret results of a trial rather than rely on exact measurements. Furthermore, resources or time required to quantify the effects of complex phenomena (e.g., weed communities, soil health) on crop yields are rarely available. If you are overwhelmed with the responsibility of using complicated methods to measure complex variables, it may be worth seeking outside collaborators (e.g., university or private sector researchers) to carry out these measurements.

While you are deciding what to measure, also consider what success means to you. For instance, how large of a change is meaningful improvement? In addition to being specific, simple to monitor, and relevant to the question, the indicators you choose should be aligned with your farm vision and goals.

For example, when evaluating whether kaolin clay and row covers could reduce flea beetle damage on eggplants relative to a control (no treatment), Ben Saunders (Turtle Farm) evaluated fruit harvest and pest damage at regular intervals throughout the harvest period. He would have done this anyway, so it took no additional effort to gather these data in his experiment, whereas measuring flea beetle populations would have been much more labor intensive.

Step F: Implement the plan

The majority of implementation tasks are essentially the same as normal farming tasks that are required for carrying out production plans each growing season. We assume that farmers using this manual understand planning and coordinating farming activities, and in the interest of sticking to our subject, we don't discuss these basics of farm management; instead, we concentrate on aspects of implementation that differ from production and are vital for getting the most out of experimentation.

F-1 Collect resources

Gathering resources in advance of planting an experiment is no different than preparing to plant crops for harvest. It can be as simple as ordering seeds for new varieties you plan to evaluate or as complex and time-consuming as modifying a piece of equipment. The main difference stems from decisions about what you will measure. Consider which new tools or supplies (if any) are necessary to collect data or monitor outcomes.

F-2 Allocate the necessary time

Allocating time for data collection is probably the most challenging aspect of successfully testing improvements on your own. It's tough to make time during the growing season to carry out measurements that are more involved than simple observation and aren't part of your normal routine. Therefore, try to work them into whatever approach you usually use to schedule farm operations. Strategies include adding research monitoring to the farm calendar, delegating this task to a trusted employee, and simply intensifying normal practices of observation. For example, Tim Sieren (Green Iron Farm) and Dick Sloan (Sloan Farm) needed to schedule their experiment in a narrow window that ensured they could frost-seed a clover cover crop before planting their corn. This required them to pay attention to weather conditions in addition to their normal farming schedule when deciding the best time to implement their experiment.

F-3 Assign roles and duties

If you plan to hand over the responsibility of managing your experiment to another person, do so before the throes of the field season. As with any other farm duties, effective delegation requires taking time beforehand to make sure your employee understands your expectations. They will be able to do a better job if they are brought on board early and understand the reasons for conducting the experiment. In fact, it's a good practice to make sure all employees are aware of any trials you are conducting to avoid accidentally disturbing the experiment. It will also allow you to reap the benefits of having even more eyes on the field.

F-4 Execute the plan

The primary goal of your experimental plots is to learn about how a change affects a crop or farming system. If you intend to learn about a management change, you can't respond to events that might detract from yields in the same way you would in fields dedicated solely to crop production. An experiment needs to be managed just as you would normally farm, except for the improvement you are testing. For instance, if you are testing a drought mitigation strategy, you can't rescue the crop with irrigation at the first sign of water stress.

If your design is a side-by-side trial (see Chapter 6 for examples), there is more latitude to intervene. In this case, you can react to growing conditions and problems as long as you do the same thing in both the control and treatment plots so the action does not unequally influence the tested modifications. For instance, if you are testing soybean varieties to find which best outcompetes weeds, the results will be meaningless if you intervene with an extra cultivation in one of the plots due to above-average early-season weed germination. On the other hand, if you are mainly interested in yield and bean quality and don't mind the additional effort involved in mechanical weed control, then responding to weed conditions will not undermine the variety trial as long as you cultivate all varieties equally.

F-5 Collect the data

Two critical pitfalls can limit the reliability of any data you collect. However, you can easily avoid them through forethought and experience. The first issue stems from relying on memory to document observations. Some farmers, particularly those who are visual learners and who are very experienced, can accurately remember observations. Their memory can serve as a dependable means of data collection and monitoring. However, most people aren't able to do this consistently, and in the course of interviews and discussions, several farmers noted situations where actual data contradicted their memory of outcomes. Thus, it is extraordinarily useful to record your observations and data in some way beyond relying on memory.

Some examples of strategies for documenting experimental results are:

- Record dates of field operations on a central calendar or in a journal.
- Avoid collecting data or observations from areas that aren't representative of the field, such as low spots or borders.
- Systematically (e.g., from the same spot, using labels) take photos of trials throughout the growing season.
- Observe the experiment at regular intervals and record your observations in a field notebook, on your phone (Box 5-4), or in journal in the evening.
- Use a small notebook that is easy to keep with you and write down all dates and observations relating to the trial (some use their phone in the same manner).
- For field data collection, make pre-formatted data sheets and take these to the field on a clipboard. This is an easy way to ensure consistency in data collection that needs to be done more than once and makes it possible for you to delegate data collection when necessary.
- Use flagging tape or surveying flags to mark where you collected samples so you can return to the same spot for repeat measures. This can be particularly useful in fields with a lot of soil variation, or if you are monitoring features that tend to be patchy, such as insect damage.

A second pitfall that can undermine your assessment of outcomes is a lack of consistency in data collection during the season or from year to year. Planning what data you want to collect and how to collect it will go a long way toward ensuring consistency during the hectic field season. For instance, you have several options for documenting the success of insect pest control practices. Deciding ahead of time whether you will use indirect (e.g., plant damage levels) or direct (e.g., abundance of the pest) metrics and then sticking with it throughout the course of the experiment is essential to maintain consistency.

For instance, to determine the effect of integrating bee-friendly pollinator habitat in different cropping systems, Sean Skeehan, Jill Beebout (Blue Gate Farm), and Will Osterholz (Mustard Seed Farm) set up bee bowls to trap and count insects. These bowls were set up in established spots on each farm, and samples were collected at regular intervals every 24 hours. The farmers then recorded the abundance of different species in tables to document their results.

F-6 Monitor the results

Regardless of an experiment's duration, periodically reviewing the results during the field season can help you spot unexpected problems that arise and react quickly. This can be critical in years when extreme weather events affect trials in ways that can undermine the experimental goal. Monitoring results can take many forms, depending on the data you are collecting, ranging from visually assessing the control and experimental plots on a weekly basis to looking at recorded data sheets of things like insect counts, labor hours, or yields for crops that are harvested continuously. Regular, detailed observation of test plots during experimentation is by far the most common approach to monitor ongoing trials.

F-7 Fine-tune the experimental management

Based on your monitoring, it may become necessary to tweak the experimental design, management practices, or data collection. Experimental designs can be more difficult to implement than expected during the planning stage, particularly if you laid out an ambitious design with multiple replications or treatments. If you are just starting to investigate a new practice, implementing a new technique may be different from what you anticipated. Alternatively, you might find that data collection is too time-consuming and just not practical. Complications like these can eventually become valuable learning opportunities or even lead to successful solutions. Just make a note of the changes you made, along with when and why you made the change. For example, when Matt and Diana Stewart (Stewart Farm) trialed a transition to a

BOX 5-4: Agricultural mobile apps.

Cell phones have transitioned from being something you would only find on Wall Street to an everyday tool that most people carry in their pockets. There are many apps that can help with tasks around the farm, including preparing maps, identifying pests, and checking prices. For a more complete listing beyond those that we describe here, check out the resources at the end of this chapter.

- agDNA: **Allows you to map field boundaries and keep records of seeding, inputs, and harvesting.**
- AgPlots: **Maintains records of crop yields for different fields.**
- Agrivi: **Monitors farm management activities and offers best practice suggestions.**
- Agrobase: **Helps identify plant pests, weeds, and diseases.**
- Calcagro: **Allows you to calculate yield rate, planting rate, seeding rate, and moisture, among other relevant measures.**
- CowManager: **Monitors cow status and health.**
- Crop Farmers App: **Describes crop-specific pests and diseases, as well as their treatments.**
- Cropio: **Uses real-time vegetation monitoring to identify problem areas and track field performance.**
- Farm Management Pro: **Records farm management activities and decisions.**
- Farmer Income & Expense Manager: **Records and analyzes farm financial data.**
- FeedMix: **Estimates nutritional content of various livestock feeds.**
- FieldBee: **Offers GPS navigation for tractors to optimize farm machinery operations and tracks data on seeding and harvesting.**
- Field Navigator: **Uses GPS to guide parallel driving during field navigation.**
- Livestocked: **Provides herd management and monitoring.**
- OneSoil: **Calculates vegetation index to determine crop health based on satellite images.**
- Plantix: **Takes photos of plant diseases to get diagnoses from a community of farmers.**
- Soil Sampler: **Locates and records appropriate soil sampling locations.**
- UNIFORM: **Helps with record keeping for cattle operations.**
- Veterinary Handbook: **Comprehensive guide on livestock disease diagnosis, treatment, and prevention.**
- Wolf GIS: **Enables mobile-ready map drawing.**

grazing-oriented operation, they realized that their cows were too thin, and so they slightly increased the grain content of their dairy cows' feed.

Adjusting management practices during an experiment needs to be done in a way that furthers the experimental goals rather than simply boosting crop yields (more discussion of this under F-4). Discussing modifications with your co-manager or other farmer staff before intervening can help to avoid accidents that undermine the trial, such as unintentionally performing normal farm operations where you are trialing a new approach.

F-8 Review success criteria

Sometimes it's beneficial to change the criteria of success if experimentation reveals flaws in your underlying assumptions about what constitutes a successful outcome. This is particularly true if your success criteria were based on a misunderstanding or a misdiagnosis of the problem. Alternatively, you may realize midway through a series of changes made over the course of several years that the outcomes you were aiming to achieve have unforeseen, negative conse-quences. For example, Anton Burkett (Early Morning

Farm, Case Study #1) initially attempted to increase his farm's profitability by expanding his production and hiring additional workers. However, he came to realize that he had not considered the degree to which this conflicted with his personal philosophy and undermined his quality of life. Hiring additional labor required him to spend more time in a managerial role, which he didn't enjoy, and less time on farming tasks. In response, he changed his criteria of success from focusing solely on profitability to including happiness as a metric. In so doing, cutting costs by downsizing his farm staff and selling equipment became a more viable and successful solution than increasing his farm's production capacity.

Step G: Evaluate outcomes

G-1 Observe the final result

Eventually the experiment will run its course. Deciding when to end your experiment depends on what you were actually testing. Sometimes, you can observe the outcome just by walking the field and looking at the trial. The process of observing an experimental endpoint is quite similar to observing your farm system. This is the last chance to gather information that can help you to interpret the results and reach conclusions about the value of the improvement you are testing.

Even if you have been routinely documenting quantitative data, it can be extremely useful to examine the experiment critically to collect any last-minute qualitative observations. You can compare side-by-side plots before crops are terminated by harvesting or tillage or (in the case of orchards and pastures) before the plants go dormant. However, sometimes the results won't be so clear-cut, and the conclusions you draw will be a bit more nuanced. For instance, perhaps the change you were testing only had a small impact, or its final effect was different from what you saw earlier in the growing season. This is when it's necessary to analyze your data.

G-2 Analyze the data

The method of data analysis you choose depends on the experimental design, the data collected, and other information you may have from observation and normal farm recordkeeping. Data analysis can be as simple as reaching a conclusion based on your final walk through the trial or as complicated as using statistics to analyze quantitative data. A majority of innovations developed by farmers arise from simple experimental designs and repeated cycles of testing. In keeping with this straightforward approach, there is rarely a need for a formalized process of data analysis. When differences between what you've been doing in the past and the tested

BOX 5-5: Principles of data analysis.

Many of the same principles of experimental design apply to data analysis, whether you are using your observations and historical knowledge of trends in key indicators (e.g., yields, farming expenses, net income) to analyze and interpret results, or carrying out statistical analysis with spreadsheets and graphing results:

- **Keep an open mind and be aware of your assumptions.**
- **Become familiar with the data. Review your notes from the trial. Look at results from any quantitative data relating to the trial.**
- **Focus the analysis. Keep your core question and the purpose of the experiment in mind.**
- **Organize information into the main categories: growing environment, management, and effects of the change.**
- **Look for patterns and trends, particularly if you have run the trial for more than one growing season.**
- **Consider other factors that could account for the results.**

modification are obvious, an informal approach that reflects your personal style will do the job.

Jill Beebout (Blue Gate Farm), Carmen Black (Sundog Farm), and Kate Edwards (Wild Woods Farm) used advanced statistical software to compare multiple replicates of pelleted seed and covered trays for summer lettuce germination. These farmers received funding from an external source, and the treatments they tested were fairly expensive to implement, demanding a more rigorous analysis. Alternatively, Jan Libbey and Tim Landgraf (One Step at a Time Gardens) used systematic observations of weeds in their fields paired with photos for record keeping to visually assess the ability of tillage radish to suppress weeds (relative to a control).

You can find examples of different approaches to data analysis in case studies and in the on-farm research manuals listed at the end of the chapter.

One simple approach to interpreting outcomes is to use observations combined with historical knowledge of trends in key indicators (e.g., yields, farming expenses, and net income). At the other end of the spectrum, some farmers use spreadsheets to organize data, carry out basic statistics, and graph results. Best practices for interpreting results are listed in Box 5-5.

G-3 Reassess risks and rewards

During the planning process, you anticipated risks and rewards based on knowledge you had before carrying out the trial. Now, with the results in hand, you can reconsider whether these risks/rewards were accurate. Everything we said about the first round of risk/reward assessment applies here, but now you have additional information to help with reassessment. In deciding to make a change, weigh the risks and benefits a solution offers in terms of time/cost, as well as how important the core question is to you.

G-4 Invite feedback

Outside feedback from fellow farmers, extension educators, and (in some cases) researchers, can be particularly valuable when you have completed a trial, assessed its outcomes, and are making decisions about a path forward. Feedback is useful at various times during the process of experimentation, so seek it whenever a second opinion would be relevant.

G-5 Determine the next steps

On-farm problem solving is nearly always a cyclical process that requires fine-tuning solutions over time through trial and error and adapting management practices based on information gleaned from these cycles of testing and fine-tuning. Outcomes that can result from testing and evaluating improvements tend to fall into three general categories:

1. You may discover a viable solution and incorporate it into your farming operation. This does not prevent further improvements as you gain more experience with continued fine-tuning in order to adapt it to field and weather variation.

2. You may find that the improvement works but isn't feasible for adoption due to ripple effects or conflicts with other parts of your system. This outcome will send you back to the drawing board to find and evaluate another potential solution that will avoid the drawbacks of the first solution tested.
3. You may conclude the test was a complete failure. If the change fails to rectify the problem, rethink your assumptions and confirm that you started with a correct diagnosis. On the other hand, if the modification solves the problem you started with but creates another, more serious problem, it may be preferable to live with the original problem.

However, in the real world, problem solving and innovation tend to take twisting and turning paths to reach a viable solution. Therefore, the process of determining next steps may not fall neatly into these three categories. For example, Chaw Chang (Stick and Stone Farm, Case Study #8) ultimately decided that it wasn't worth the effort and cost of purchasing additional new equipment to continue improving his raised bed vegetable crop system. Another farmer might have decided that this was something he wanted to pursue, and Chaw may have agreed if the potential solutions were cheaper to implement.

G-6 Share results

Sharing what you learn from experimentation helps build the general body of agricultural knowledge. Thor Oechsner (Oechsner Farms) pointed out that if you have a problem, odds are that someone else is having the same issue. Helping other farmers avoid these pitfalls and problems allows them to focus their efforts on further improving and refining new solutions, which they can then communicate to others in turn. Furthermore, by sharing results, you can receive feedback about possible improvements or tweaks you can try on your farm. Conferences, farmer meetings, and extension research reports all provide great outlets to share your findings.

Recommended resources

On-farm research

For farmers

- Baldwin, K. R. (2004). A Field Guide for On-Farm Research Experiments. Greensboro, NC: Cooperative Extension Program at North Carolina A&T State University.
- Hilshey, B., Boswoth, S., & Gilker, R. (2013). A Practical Guide to On-farm Pasture Research. The University of Vermont.
- Kansas State University (2016). Agricultural Mobile Apps: A review and update of scouting apps. Manhattan, KS.
- Madsen, B. S. (2016). Statistics for non-statisticians. New York, NY: Springer Berlin Heidelberg.
- Nielson, R. L. (2008). A Practical Guide to On-Farm Research. Lafayette, IN: Purdue Univ.
- Rempel, S. (2002). On Farm Research Guide. The Garden Institute of Alberta.
- Sooby, J. (2001). On-Farm Research Guide. Organic Farming Research Foundation.
- Sustainable Agriculture Research and Education Program. (2017). How to Conduct Research on Your Farm or Ranch.

For extension agents and researchers

- Drinkwater, L. E. (2002). Cropping Systems Research: Reconsidering Agricultural Experimental Approaches. HortTechnology, 12(3).
- Drinkwater, L.E. (2016). Systems Research for Agriculture: Innovative Solutions to Complex Challenges.
- Richard, Thompson S (1990). The on-farm research program of Practical Farmers of Iowa. American Journal of Alternative Agriculture 5:163.
- Rzewnicki PE, Thompson R, Lesoing GW, et al (1988). On-farm experiment designs and implications for locating research sites. American Journal of Alternative Agriculture 3:168.
- Sumberg J, Okali C (1988). Farmers, On-farm Research and the Development of New Technology. Experimental Agriculture 24:333.
- Zandstra H, International Development Research Centre (Canada) (1986). A Methodology for On-farm Cropping Systems Research. International Development Research Centre, Ottawa.

Comparing risks and rewards

- Brouwers, J., Prins, E., & Salverda, M. (2010). Social Return on Investment: A practical guide for the development cooperation sector. Utrecht: international cooperation, Utrecht.
- Ray, A. (1990). Cost-Benefit Analysis: Issues and Methodologies (No. 11597). Baltimore, MD: The World Bank.
- Turpin, N., Laplana, R., Strauss, P., Kalijonen, M., Zahm, F., & Begue, V. (2005). Assessing the cost, effectiveness, and acceptability of best management farming practices: a pluridisciplinary approach. Rennes cedex, France: INRA.
- Zhou, X., Helmers, M. J., Al-Kaisi, M., & Hanna, H. M. (2009). Cost-effectiveness and cost-benefit analysis of conservation management practices for sediment reduction in an Iowa agricultural watershed. Journal of Soil and Water Conservation, 64(5), 314–323. https://doi.org/10.2489/jswc.64.5.314

6 Example experimental designs

In this chapter, we present several possible experimental designs, starting with the simplest and ending with the most complex. We discuss the strengths and limitations of each and provide detailed examples of how plots could be arranged. There is no such thing as a universal design that is right for every attempt at on-farm problem solving and innovation. We will use a hypothetical organic vegetable farm as an example, focusing on 11 fields (Figure 6-1). Fields are managed in an intensive rotation of vegetables and annual cover crops. A soil type transition runs diagonally across the farm, with a loamy well-drained soil in the western fields shifting to a heavier clay loam in the northeast. These fields have areas with poor drainage (E1, C1, and W1) and, as a result, the farmers grow a different mix of crops in these fields.

Trials repeated over time without a control or replication

Farmers commonly use an iterative process to modify their farming system and achieve a desired goal. While testing a management change without comparing it to your current practices has drawbacks, there are instances when having a control treatment may not be

> An **iterative process** uses a repeated cycle of operations to achieve a desired result. The more times you perform the cycle, the better the result should become.

FIGURE 6-1: Map of the farm we use for experimental design examples. Fields are labelled E, C, and W for east, center and west and numbered from north (lower numbers) to south (higher numbers). The dotted white line is the soil type transition.

useful. In these instances, farmers find it more effective to concentrate their efforts on making the system or practice work on their farm.

For example, if you decide to transition to a completely different management system that is already being used by farmers in your area (e.g., no-till or organic farming), you may not be interested in comparing the new system to your current management. This was the case when Adam and Courtney Squire (Case Study #10) decided to fully transition their farm to no-till. They didn't do any controlled tests to compare their then-current production system to no-till, in part because they had many examples of farmers who had successfully made the switch. Adam and Courtney relied heavily on those individuals for assistance and guidance.

Low risk/low cost modifications with limited impact on crop yields are commonly developed using this informal process. The focus on repeated cycles can be particularly effective for management-intensive improvements that require lots of tweaking through trial and error. For example, Chaw Chang (Case Study #9) had to go through four rounds of experimentation before he settled on a reasonably satisfactory solution to his weed problem.

Lastly, farmers commonly use an iterative process when the desired management change is a priority regardless of how it affects yield or income. Karma and Michael Glos (Case Study #8) were set on breeding organic chickens from organically raised chicks. They didn't bother with a control because of their dedication to making the change work regardless of any hiccups they would encounter along the way; they weren't going to abandon their efforts just because it did not maximize profit or didn't immediately succeed.

Although iterative trials have their place in on-farm problem solving and innovation given how easy they are to do, there are pitfalls that can outweigh their simplicity. One drawback of iterative trials is that when problems arise, it can take several cycles to diagnose and correct them. For example, differences in soil or weed populations across a farm combined with differences in the weather may cause year-to-year changes in the performance of the trial. Without a control plot, it may be

FIGURE 6-2: **Experimental design for a sequential, unreplicated, uncontrolled variety trial. The experimental plots are highlighted and numbered for each year they were planted.**

difficult to determine the cause of year-to-year variation.

In the early stages of trying a new system or introducing a new practice or crop, a quick trial just to get experience with new management activities is perfectly fine. Later in the process, when you are optimizing the system/practice, side-by-side trials that compare adjustments to a control (as described below) provide more definitive feedback that will allow you to better diagnose problems and make appropriate adjustments across your farm. Also, if there are two different possibilities that you want to consider (i.e., two different varieties or two different cover crops), iterative trials of one and then the other could lead to faulty conclusions if there are differences in environmental conditions from one year to the next.

In the case of our example farm, assume the farmers want to introduce a new vegetable crop that their customers have been raving about. Because these farmers don't have any experience growing this kind of crop, there's no point in having a control; they don't have a crop they're currently growing that could be a point of comparison. They could plant a single variety of the crop in the trial, and this is fine if they are able to talk with other framers in the area who are growing the crop and can provide guidance or share which variety works for them. Alternatively, it is easy enough to include two to three varieties in a single plot to determine which varieties work best on their farm.

To increase their chances of success, our farmers decide to plant three varieties in field W3 for their first trial (Figure 6-2). They decide against collecting quantitative data, instead choosing to focus on differences they can observe. They choose their first experimental plot location because it is close to their buildings and easy to monitor, in addition to having more uniform soils. In this first growing season, they find that variety #2 has noticeably greater yields and is preferred by customers.

In year two, they rotate the trial to field W5 and improved their weed management based on their experience from the first season. As a result, all three varieties' yields increase, but #2 continues to stand out in terms of productivity and customer preference.

The following year, they plant all the trial varieties again, this time in field C4. Several hot spells seem to trigger a pest outbreak. Although all three varieties suffer, the

previous frontrunner (variety #2) appears to be the most susceptible of the bunch.

Ultimately, the farmers decide that the series of trials has allowed them to perfect their mangement of the new crop; however, it did not reveal a consistent, clear-cut best variety. At this point, their decision about whether they want to invest more time in improving the performace of this crop through variety trials would depend on their priorities (i.e., yield or customer preference) and management options, (i.e., opportunities for controlling the pest problem that emerged in year three).

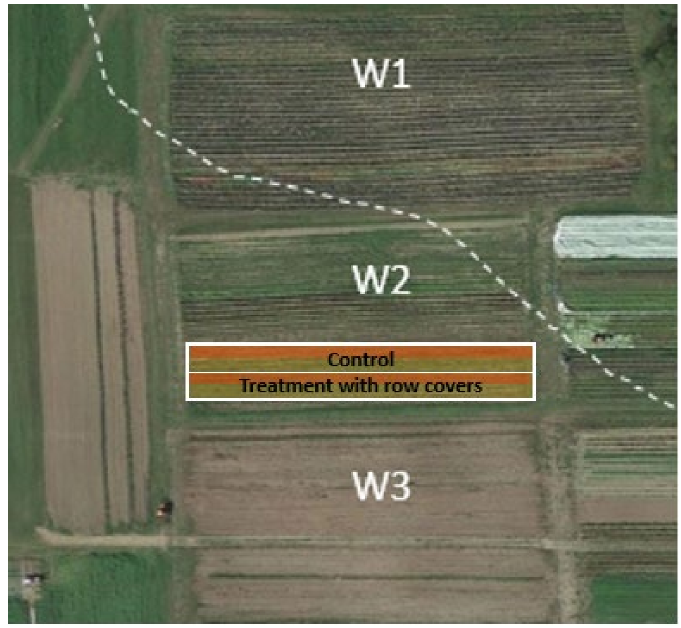
Unreplicated side-by-side comparisons with a control treatment, repeated over time

Side-by-side comparisons that include a control require slightly more investment of time and resources, but the extra effort up front can save time in the end and help to avoid misguided conclusions. A "control" or "check" is simply the treatment without the change you are interested in evaluating. For example, if the goal is to test a different soil mixture for starting seedlings, your control would be flats containing your standard mixture, and the experimental treatment is the new mixture. To compare these, the control and experimental treatment must be compared in the same period, and all other conditions between the two must be the same, including the seeds used, environmental conditions, watering, and any other management practices.

Side-by-side trials are really the only way to reliably test a new purchased product to determine if it actually works. For example, when trying a new worm treatment for livestock, you must compare animals with and without the medication and keep everything else the same (e.g., feed, supplements). If you want to try a microbial inoculant that claims to enhance root growth, you must compare the same crop with and without the additive in side-by-side plots, under identical management.

> To compare these, the control and experimental treatment must be compared in the same period, and all other conditions between the two must be the same.

FIGURE 6-3: Detailed view of the experimental layout for the first side-by-side trial with a control treatment (year 1).

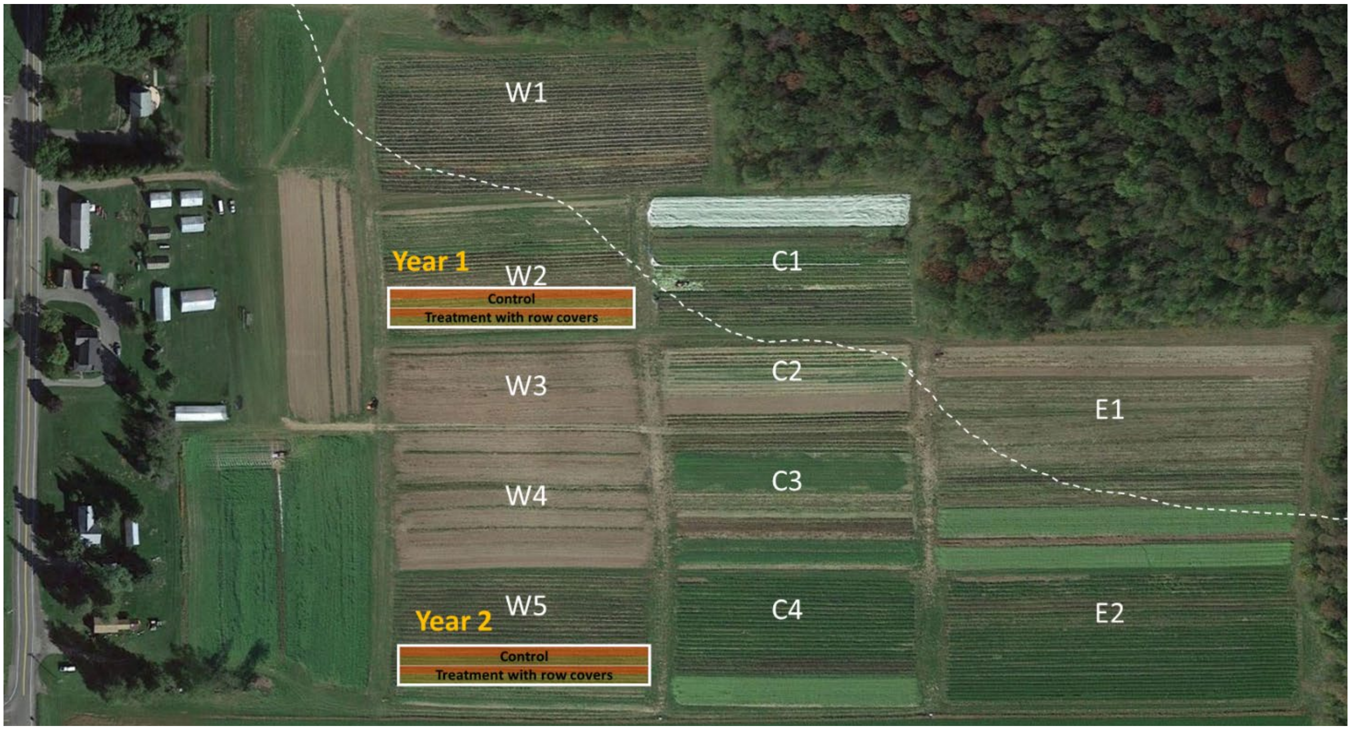


Let's return to our example farm, where the farmers have decided to continue testing variety #2 in order to resolve the pest problem that they observed in the third year. After talking with other farmers, they learn that using row covers during establishment can help control the pest. To test this, they set up a side-by-side trial (Figure 6-3) with a control (no row cover) and an adjacent experimental treatment (row covers after transplanting).

They decide to hedge their bets by continuing to grow more than one variety, but they limit the trial to the best two varieties from the first three rounds (varieties #2 and #3). In addition, because using the row covers requires more work, they decide it will be worthwhile to collect yield data to make sure the change is worth the labor costs. To make this manageable, they carefully weigh and record yields from the first and last harvests. They find that variety #2 again had higher yields compared to #3, but there was no difference in yields or quality between the control and row cover treatment. They attribute this to the fact that they did not observe the pest on the crop this year.

They conduct the same trial for a second year (Figure 6-4), this time rotating it into field W5 where the trial is planted after the same crop as in year 1. They keep all practices as similar to year 1 as possible (i.e.,

FIGURE 6-4: Whole farm view of locations for both side-by-side trials.



transplanting date, spacing) to minimize year-to-year differences. They also use the same management/data collection in both treatments. This year, the workers notice the pest during the first harvest. Yield data reveal that, under row cover, yields of variety #2 were higher than variety #3. The crops under the row cover produced more yields than those in the uncovered plots. In the control plots, without row covers variety #3 yields were higher than variety #2, which had the lowest yields of all. From these results, the farmers conclude that row covers are beneficial for both varieties of this crop, but they are most beneficial for the higher-yielding, tastier variety (#2). If the farmers hadn't repeated the trial a second time, they would have come to the wrong conclusion!

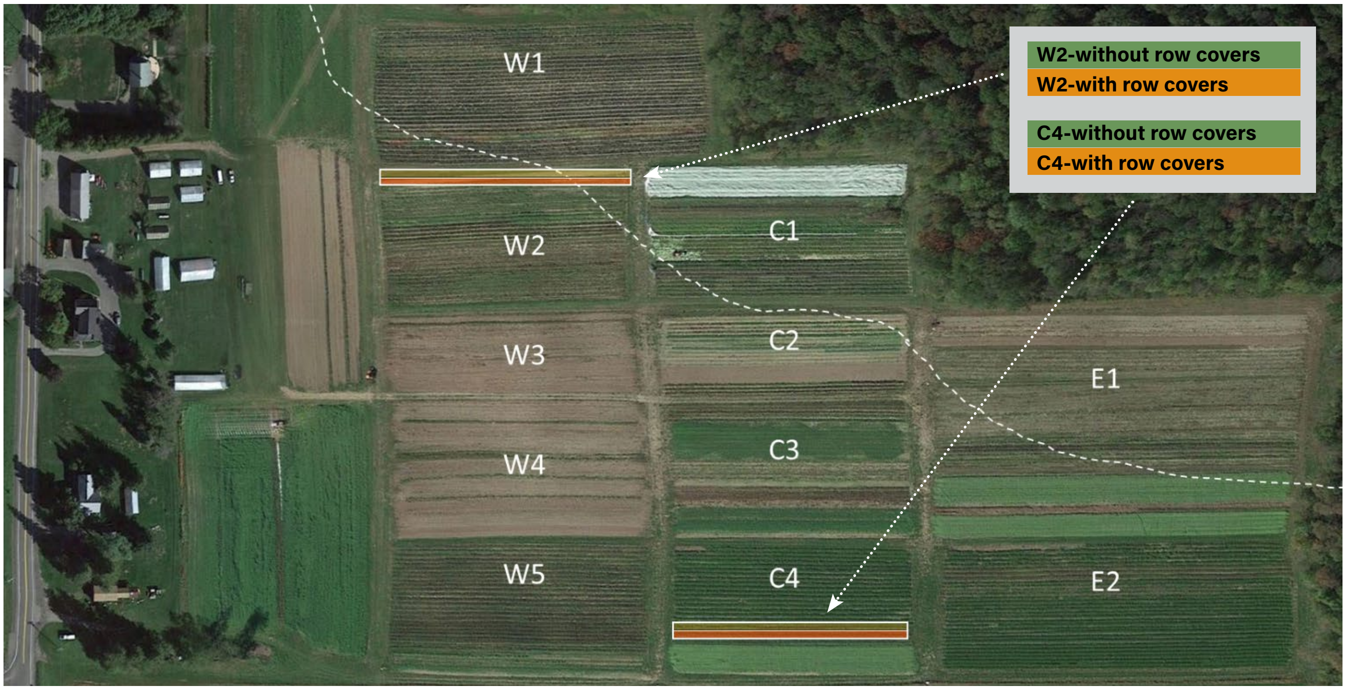
Side-by-side comparisons with a control treatment, replicated in multiple fields

Having a control is necessary to identify whether a change actually has a meaningful effect, or whether it was due to something other than the management change in question. In many situations, using side-by-side comparisons with a control and replicating it over time is sufficient for making management decisions. However, if the management practice is affected by seasonal variation or environmental variation across fields, you may need to replicate trials within the same growing season in order to answer your question. Frequently, two replications are adequate, but, depending on your question, you may want to establish replicate trials in more than two fields.

Let's return to our farmers to illustrate this experimental design. The row covers help them successfully grow the crop when the pest was present, but it is a costly change both in terms of time and money. What's more, they still aren't sure why the pest outbreak occurred in the second year of the row cover experiment when the weather conditions were similar to those of the year before because there were no unusual hot spells this time. Something else has to have been causing their pest problems.

The farmers notice that the pests seemed only to occur in the southernmost fields. The farmers had initially thought the pest outbreak was due to weather conditions, but maybe it was due to something specific to that area? During their next farm walk, they search the border of their southern fields and the neighboring alfalfa crop for the pest. They find evidence of a small number of these insects. After looking at the past performance of the new crop since they first began growing it on their farm, they develop a hypothesis: that

FIGURE 6-5: Controlled, side-by-side trial with (orange) and without (green) row covers with two replications, one in field W2, the other in Field C4.



their neighbor's field is serving as a source of the pest. To test this, they perform controlled side-by-side comparisons replicated in different fields.

They plant side-by-side trials in two of their fields, one far from the southern border (W2), and the other very close to the neighbor's alfalfa field (C4, Figure 6-5). These two fields are on the same soil type, and they place the plots in areas within each field that had been in the same crop in the previous growing season. By running the trial at two locations in the same growing season, they can test their idea that proximity to the neighbor's field was the source of this pest. This design ensures that they can directly compare the fields at different locations and rule out other causes of differences in pest pressure such as variation in weather or other chance events that might differ between years.

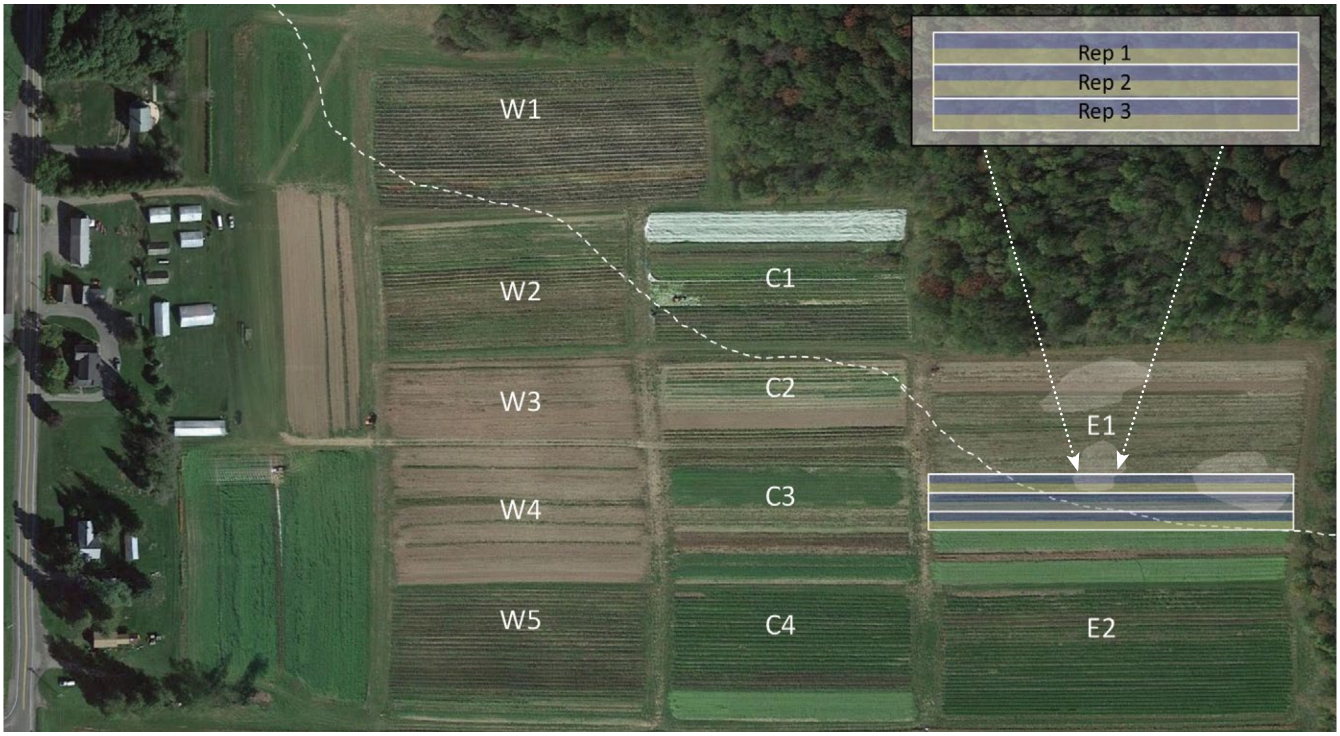
Having settled on which cultivar works best for them, they exclusively plant variety #2. To ensure that they have a market for the increased production of this crop, they expand their marketing to local restaurants and land a couple of contracts to supply the crop to these businesses. Just as before, the control is left uncovered while the treatment plot is covered to exclude the pest. However, rather than quantitatively measure yields, they decide to qualitatively gauge pest damage. This is much quicker and easier to assess while also giving them the data they need to assess their pest problem.

Just as they expected, they see the pest in field C4 early in the season, and when it comes time to harvest, the plants in the control plot have significant damage, while the ones under the row cover are in good condition. However, they find something quite different in W2. There, both the covered and uncovered crops are more or less unscathed, demonstrating that the pest damage was a result of the proximity to the neighbor's farm. It also indicates that they might not have to use row covers to control the pest across all of their fields, instead only doing so when they plant that crop on the southern part of their farm.

Side-by-side comparisons with a control treatment replicated in a single field

At its core, replication is a way of accounting for variability over space and separating these effects from seasonal differences such as weather or pest populations. If you are concerned about whether a solution to a problem will work across the entirety of your farm, it is necessary to replicate in multiple fields, as we described above. However, replication within a field is helpful when you're trying to fine-tune practices so they are optimized

FIGURE 6-6. **Controlled, replicated side-by-side trial within a single field. The insert shows the detailed layout of the controls (green) and row cover treatments (blue). Poorly drained areas noticed by the farmers in previous years are indicated by white areas in field E1.**



for all your fields that have similar environments. This can be particularly useful if you have rented fields that are distant from your main farm. Replicating within a single field closer to home can help you to fine-tune management practices that can then be applied to similar, more distant fields. Another situation where replication within the field is the most effective approach is in problem fields with variable soil or weed conditions across the field.

Take, for instance, our farmers who have steadily improved their management of a new crop over the course of six growing seasons. They have perfected their production techniques and expanded their market for the crop. At this point, they are interested in determining if they can introduce the crop to their more problematic fields that have heavier, more variable soils (W1, C1, and E1). Some of their vegetables do not perform well in these fields, particularly in the areas with poor drainage, so their rotation options in these fields are more limited compared to fields on loamy soils.

They decide to conduct a controlled, replicated experiment to evaluate whether this crop can do well in these soils with varying drainage. This time, rather than replicate in multiple fields, they decide to do so in a single field with known areas of poor drainage. They choose an area in E1 that had been used to raise the same crop the previous season, followed by the same overwintering cover crop.

Once again, they decide to hedge their bets by evaluating more than one variety. At a recent winter meeting with other farmers, they learned about another variety of the crop in question. This cultivar is better adapted to the conditions of the Northeastern United States. A couple of farmers had tried growing the new crop variety and report that it seemed to be more tolerant of wet conditions. Based on this new information, the farmers think it would be a good idea to evaluate this cultivar at the same time they test the performance of variety #2, their favored cultivar. They design a trial aimed at answering two questions. First, could this crop be grown in their fields with variable, poorly drained soils? Furthermore, could the new variety improve performance in poorly drained soils compared to variety #2?

Since the field is far enough from the southern border, they do not expect to need row covers. They establish three replications, with side-by-side treatments of variety #2 (control) and the new variety (variety #4, Figure 6-6).

FIGURE 6-7: Example map of randomized, complete block design.

Block 1	Block 2	Block 3	Block 4
Treatment 1	Treatment 3	Control	Control
Treatment 3	Treatment 1	Treatment 2	Treatment 1
Control	Treatment 2	Treatment 3	Treatment 3
Treatment 2	Control	Treatment 1	Treatment 2

They arrange the plots so that the western end is on the loamy soils, while the eastern end of the plots is on the heavier soils for all three replicates. Sections of Rep 1 and 2 have spots known to have poorer drainage compared to the rest of field E1. To evaluate crop performance in the different soils, they observe crop growth and take photos of the east and west ends of each plot during the growing season. At harvest, they measure yields for two 10-foot row lengths in each plot.

They find that yields of both varieties are greater in the western end of the plots compared to the east where the soils are heavier and poorly drained. The differences between east and west are greater for variety #2 because variety #4 performed better in the eastern section of the plots. In the loamy soils, variety #2 was still the best performer.

Now, after seven growing seasons, they have increased their ability to grow this crop across their entire farm, adding a new opportunity to diversify rotations on their problematic fields and developing a new, lucrative market for a crop that they can dependably produce. The result of each experiment informed what they did the following year. Based on these repeated experiments, they were able to find a new crop that their customers love and that performs well on their farm, to find a solution to a pest that threatened one of their most profitable enterprises, and to fine-tune it to maximize their profitability.

Randomized, complete block designs

The randomized, complete block design (RCBD) is the most common experimental design used by agricultural researchers. This formal experimental approach always includes a control and commonly involves more than one experimental treatment. The entire experimental site is divided into several blocks, which are then further subdivided into plots. Each treatment is applied randomly to a plot so that each block contains all treatments and a control (Figure 6-7). Several resources offer additional details on the use of RCBDs in farm systems (Box 6-1).

RCBDs can require considerable time and resources to implement and monitor. Farmers do not typically use this design unless they have support from scientists or extension educators. For instance, Klaas Martens worked with Cornell University's George Abawi (Case Study #5) to perform an RCBD to find the cause of his root rot and test potential solutions. Practical Farmers of Iowa's website offers technical reports that detail several examples of farmers implementing this design (e.g., Scott Shriver testing different soybean row widths and seeding dates, or Jack Boyer and Tim Sieren evaluating different cover crop termination treatments), but most involve collaborations with extension educators or researchers.

BOX 6-1: Selected extension resources detailing the use of RCBDs in farm systems.

- **Davis, R. F., Harris, G. H., Roberts, P. M., & MacDonald, G. E. (2017). Designing Research and Demonstration Tests for Farmer's Fields. Fort Valley, GA: University of Georgia Extension.**
- **Kyveryga, P., Mueller, T., Paul, N., Arp, A., & Reeg, P. (2015). Guide to On-Farm Replicated Strip Trials. (A. Arp, Ed.) Guide to On-Farm Replicated Strip Trials. Ankeny, IA: Iowa Soybean Association.**
- **Marini, R. (2016). On Farm Research. State College, PA: PennState Extension.**
- **Rzewnicki, P. (1992). On-farm Trials for Farmers Using the Randomized Complete Block Design. Lincoln, NE: Nebraska Cooperative Extension.**

7 Case studies

The following case studies are real-world examples of farmer experimentation. As demonstrated in these case studies, the path to problem solving and innovation is often non-linear and rarely progresses neatly through the steps and tasks we presented in this manual. The farmer-innovators we interviewed tend to follow the general process described in this manual, but many skipped steps or implemented them out of order in response to the particular problems they were targeting. This flexibility is a key characteristic of on-farm problem solving, and the ability to tweak the cycle of experimentation increases with experience.

For each case study, we present some background about the farmers and their farms, the problems they attempted to solve, their methods for doing so, and the results of their efforts. We also summarize some general lessons that can be gleaned from the case. Although we have attempted to tie these narratives explicitly to the Problem Solving and Innovation Framework, our primary goal is to share the farmers' stories. The farmers often highlighted particular aspects of the process they used to solve a problem or to carry out the more ambitious undertaking of developing an entire cropping system. As a result, each case study does not provide detailed coverage of all steps and tasks outlined in the Framework.

CASE STUDY 1

Setting goals and determining quality of life requirements
(Anton Burkett, Early Morning Farm)

Farmer Profile: Anton founded Early Morning Farm in 1999. Since then, it has grown to one of the largest organic CSA farms in the Northeast. The farm mission is to provide food that is grown in a socially, economically, and environmentally sustainable way. Early Morning Farm subsidizes some CSA shares for low-income families, making healthy, local food accessible, particularly in underserved neighborhoods that generally cannot obtain it.

Everything originates with defining a farm vision
(Task A3: page 17)

One of Anton's early goals was to increase his farm's net income. He initially tried to meet this goal by expanding his farm and increasing the number of CSA shares he offered; this expansion required him to hire additional workers. However, having made these changes, he found that the increased scale of his farm operations required him to take a more managerial role, which he didn't enjoy.

Use resource inventories to identify waste
(Task B2: page 21)

Anton remained steadfast to his goal of improving the profitability of his farm. However, he knew that he could not continue to achieve it by continuing to increase the size of the CSA. Instead, he shifted his goals away from increasing gross income to focus on increasing the efficiency of his farm operations and business. He started to downsize by renting less land, laying off workers, and selling unnecessary equipment.

Analyze records
(Tasks D2-3: page 35)

Keeping records of labor hours dedicated to different farm operations allowed Anton to identify which ones offered the highest returns with the least amount of work. Based on this information, he decided to shift his market strategy such that he sent fewer workers to staff less-profitable farmers' markets. Finally, he cultivated more high-value crops that were profitable and popular based on his financial records and customer feedback, respectively. That said, he also needed to ensure the resilience of his farm system and customer satisfaction by maintaining crop diversity. Balancing these tradeoffs "is a continuous process," he noted.

FIGURE 7-1: Anton at his Ithaca Farmers' Market stand.

Photo courtesy of Karen Whetzel and Anton Burkett.

Insights: You, too, can become an innovator/expert problem solver!

- **Be clear about your farm vision:** Anton ran into problems when he pursued his farm vision (i.e., being actively engaged in maintaining a profitable farm). His initial decision to increase production to enhance profitability conflicted with his desire to remain engaged in day-to-day farm operations. As a result, he needed to find new goals (reducing waste and inefficiencies) that would allow him to fulfill his vision without negatively affecting his quality of life.
- **Intangible goals matter, too:** While farm goals are often focused on benefits like yields, income, and waste, it is also important to consider intangible outcomes, such as your enjoyment of the work. Quality of life is crucial for sustainable farm management; otherwise, it is easy to burn out. Anton knew something needed to change once he stopped enjoying working on the farm. As he told us, "If it's not fun, it doesn't matter."
- **Analyze your financials to minimize waste:** Analyzing your financials is important to determine whether or not you have the resources to tackle a problem. However, it can also be useful to identify costly expenditures and unprofitable operations that you could cut down on to reduce financial leaks and wasteful spending.

CASE STUDY 2

Observing patterns

(Jean-Paul Courtens and Jody Bolluyt, Roxbury Farm)

Farmer Profile: Jean-Paul bought the first five acres of what is now Roxbury Farm in 1990. Over the past three decades, the farm moved to Kinderhook, NY, and grew to 400 acres. He and Jody cultivate 30 acres of vegetables that support their CSA. They also cultivate hay and pasture on half of their acreage, which goes to feed their cows, sheep, and pigs. All their farm products are certified organic, and the Northeast Organic Farming Association of New York honored them with the Farmers of the Year award in 2018 for their efforts. They have partnered with the Open Space Institute and Equity Trust to ensure that the farm is protected for sustainable agriculture. Jean-Paul and Jody encourage community members to visit their farm by hosting social gatherings, dinners, and school field trips. They also invited researchers from Cornell University to study the effects of their bell bean management. This collaboration helped both groups better understand how to manage agroecosystems sustainably.

Serendipitous observations while walking the farm

(Tasks C1-3: page 28)

Fifteen years ago, Jean-Paul and Jody wanted to offer some new early season vegetables to their CSA members, so they tried cultivating an acre of fava beans. They ultimately decided against growing these beans in subsequent years because customers didn't particularly care for them, and the seed was expensive. However, they noticed that broccoli was extraordinarily productive when it was grown in the fields where fava beans were previously cultivated. The beans seemed to boost yields more than any other cover crops they had used in the past (e.g., chickling vetch and peas). Jean-Paul and Jody believed this to be partially a function of the beans' nitrogen fixation, which was a limiting nutrient in their soils, but they weren't sure whether this

FIGURE 7-2: Jean-Paul noticed that broccoli grown after beans seemed extraordinarily vigorous!

Photo courtesy of Johannes Courtens.

was the only reason for the effect on broccoli yields. Regardless, they decided to find an alternative lower-cost leguminous cover crop that could cultivate in the early spring and would offer similar yield and quality improvements for subsequent crops, including broccoli.

Consult experts and investigate the subject

(Tasks D8, E1: pages 37 and 40)

Knowing that there is a large body of research regarding green manures, Jean-Paul consulted old texts, including *Organic Principles and Practices* by Adrian Pieters, which explained that bell and fava beans were different cultivars of the same species and would likely function similarly to one another, even if the bell beans weren't as marketable. Bell bean seeds were also smaller than fava bean seeds, so it would be cheaper to cultivate the former on a per-acre basis. Jean-Paul learned that California farmers often use bell beans as winter cover crop, so he suspected they could be cultivated during the spring in New York. Seed dealers, however, advised him against the experiment because bell beans weren't widely cultivated in the Northeastern United States. Unheeded, Jean-Paul planted five acres of bell beans. "We already planted fava beans at a smaller scale," he said, "and the effect was so significant that we figured we could jump right to large-scale implementation with the bell beans."

FIGURE 7-3: Jean-Paul and Jody's bell bean-field pea seed mix.

Photo courtesy of Johannes Courtens.

Fine-tune actions

(Task F7: page 50)

Jean-Paul and Jody first exclusively planted bell beans, but the lack of ground cover early in the season allowed weeds to become a problem, so they tried adding field peas and oats in the next growing season. This helped reduce weed populations to some extent, but the oats tended to go to seed before they could terminate their cover crops and grew as weeds themselves. Jean-Paul and Jody now use a mix of field peas and bell bean seed, which meets their objective of increasing ground cover to prevent erosion and weed control.

Insights: You, too, can become an innovator/expert problem solver!

- **Luck has a lot to do with it, but only if you are observant:** Although it was pure chance that they first tried to plant fava beans, Jean-Paul and Jody may have simply abandoned the idea altogether if they hadn't been observant enough to notice the effect of planting beans before broccoli.
- **The experts aren't always right:** Jean-Paul chose to rely upon his own experience as opposed to heeding the advice of seed dealers. It's not that consulting with experts is a waste of time; in fact, it is a good idea to do so. However, just be aware that their knowledge is typically drawn from generalized experimental research as opposed to the experiences of unique individuals. Don't be afraid to trust your own anecdotal evidence. That said, just because it worked for another farmer doesn't mean it will work for you. It's tricky to strike a balance between being open to novel, untested ideas and relying on tried-and-true approaches.
- **Adaptive management is a repetitive process:** Jean-Paul and Jody evaluated several combinations of cover crops alongside bell beans before settling on a final mix rather than changing their criteria for success.
- **Constraints from values can force creative innovations:** "Everything we do is aimed at reducing inputs," Jean-Paul said. This curtails both the fiscal and environmental costs of farm management. The soils on their farms had high concentrations of potassium and phosphorus, so nitrogen was the limiting factor. Cultivating bell bean before broccoli, spinach, and arugula eliminated their need for nitrogen fertilizer, which also reduced their production costs.

CASE STUDY 3

Developing a cropping system and a unique market niche

(Thor Oechsner, Oechsner Farms)

Farmer Profile: Thor began pursuing his passion for farming as a child by raising vegetables in his parent's suburban yard. In 1991, he bought a 15-acre farm in Newfield, NY and started commercially growing organic grains. He initially supplemented his farm income by working as a car mechanic and teaching at a local BOCES. However, by 2003, he expanded his farm to 1,200 acres and transitioned to farming full-time. He cultivates a variety of grains, primarily for human consumption, including wheat, rye, and corn, which he then either mills himself or sells to flour mills, bakeries, distilleries, and breweries. He also helped finance, construct, maintain, and manage a farmer-owned grain mill. Thor offers tours of his farm and regularly helps Cornell researchers.

Identify your farm vision and target market

(Tasks A4-5: Page 18)

Thor began his farming career by growing primarily animal feed crops. However, he soon realized that growing higher-value crops for a unique market niche could be a good strategy for improving net profits above those generated from animal feed production. He settled on growing food-grade small grains, including high-protein wheat for bread baking. Thor knew that most wheat used for flour is grown in the central United States because of the region's relatively hot and dry weather. At the time, very few people were trying to cultivate it in the Northeast because the wet weather conditions during harvesting can cause *Fusarium* seed head blight, making the grain unsuitable for human consumption. He knew he would need to find wheat cultivars that were adapted to the climatic conditions of the region.

FIGURE 7-4: Thor seeding his organic grain fields.

Photo courtesy of Rachel Lodder.

Background investigations

(Tasks B4 and E1: pages 25 and 40)

Unheeded by the uncertainties involved in this project, Thor used extension organizations—such as the Organic Grain Research and Information Network, Cornell University Agricultural Extension, and the University of Vermont Extension—to investigate how to grow wheat for the bread baking market. Based on this research and consultations with wheat farmers in Quebec and Vermont, he identified several varieties of promising wheat cultivars suitable for Finger Lakes region.

Design actions: Two-step assessment of wheat varieties

(Tasks E5 and G4, pages 43 and 53)

Thor established primary criteria (namely protein content and resistance to the *Fusarium* head blight that affects small grains) for choosing promising wheat varieties to grow on his farm. He then performed field trials of different varieties and rotations to determine the most productive grains and management strategies. Thor also knew that he needed to find grains that his end users would want to buy. To assess this, he sent flour samples made from the most agronomically successful cultivars to bread bakers in New York City. They helped him identify varieties that would be desirable for their baking qualities and taste, in addition to their productivity.

Determine next steps

(Task G5: page 53)

After identifying the most productive, tastiest varieties, Thor carried out a multi-year process of testing a variety

FIGURE 7-5: **Thor teaching Cornell University students about crop rotations and cover cropping.**

Photo courtesy of Tomasz Falkowski.

of management strategies that would maintain grain quality and minimize post-harvest losses (e.g., harvest time, drying techniques, testing for moisture in order to determine how the harvested grain needed to be handled).

Insights: You, too, can become an innovator/expert problem solver!

- **Remember the end user:** Finding productive, *Fusarium*-resistant wheat varieties wouldn't have been particularly useful if they weren't desirable for the bakers and brewers who would be buying and using Thor's flour. It is often a good idea to monitor several criteria for success (including measures of both quantity and quality) to determine which solution is the most appropriate for your farm system.
- **Long-term documentation is important:** The large size of Oechsner Farms makes monitoring a challenge for Thor. Every year, he fills a notebook with a wide range of details about his farm, including weather, financial records, seed lists, and general observations. His deep knowledge of the property helps him understand where to focus his attention. Organized record keeping is particularly crucial to identify long-term impacts of changing farm management over multiple years.
- **The farmer is a jack-of-all-trades:** Having diverse perspectives facilitates finding novel solutions to complex problems on the farm by integrating disparate ideas. Thor's background as an auto mechanic helped him deal with simple, mechanical issues on his farm so he could focus on other, more complex problems.

Notes in Hindsight

To succeed in this complex endeavor, Thor developed record keeping and data analysis skills that enabled him to track outcomes and interpret results. He recorded yields and losses to spoilage due to Fusarium every year to evaluate how his grain drying and storage impacted his farm's productivity and profitability.

CASE STUDY 4

Adapting to climate change through innovative management
(Lou and Merby Lego, Elderberry Pond Farm)

Farmer Profile: Lou and Merby Lego have been farming near Auburn, NY, for 35 years. They have about 100 acres, including vegetables, pasture, forest, herbs, cut flowers, and apple trees. They raise heritage pigs and chickens. Elderberry Pond Farm's most unique feature is not a crop, however—it's their restaurant! Their son Christopher trained as a chef and came back to the farm to start a now-beloved farm-to-table restaurant that features meat and vegetables produced on-site. Running a restaurant changed the way Lou farms—because the food is needed so often and for so long, succession planting is essential. Approximately 70% of the food produced on the farm goes to the restaurant! Lou has shared this discovery at conferences, at SARE workshops, and with farmers coming to visit the farm and see his setup. He is also working with researchers at Cornell University to conduct formal scientific research at his farm.

Observe patterns from the records

(Tasks C2-C5, page 28)

Lou noticed that precipitation patterns have become increasingly erratic, with large rainstorms that flooded his flat fields and washed out seeds, followed by hot, dry spells that hardened the soil. He verified his observations by examining data from the United States National Oceanic and Atmospheric Administration's National Climatic Data Center.

He made several attempts to address the flooding in his fields; he cleaned and expanded his drain tile system and tried using different mulches. Neither of these approaches fully solved his problem; the only crops that were growing well in these conditions were hilled potatoes. Inspired by this, he attempted to address the flooding problem by hilling his crops. This helped during wet periods but created another problem; the hilled soil dried out quickly in drought conditions. After this trial failed, he needed to find another solution.

Lou considered installing an irrigation system, but this would have been expensive. He encountered a journal article about using "wicking hills" in developing countries. The technique relied on hills made from wicking materials covered with soil that would draw up water during dry periods. The article was largely theoretical, and the technology hadn't been fully evaluated, but based on his engineering background, Lou hypothesized that the method would work in his fields. He decided to test it out.

FIGURE 7-6: Evidence of some of the drainage problems Lou faced in the summer of 2018.

Photo courtesy of Lou Lego.

Design a trial and review the results

(Tasks E5-F6: page 43)

To rapidly evaluate the effectiveness of the wicking hill technology, Lou initially used oat straw as a wicking material in several rows, and covered it with soil to form hills into which he planted crops. The wicking material effectively drew water closer to crops during dry periods, and the hills shed water into the cover crop strips between the rows during wet periods.

Based on the success of this initial trial, Lou applied for and received a SARE grant to further test this technology. He designed and implemented a replicated experiment. He laid down oat straw in several 200-foot-long rows (the length of the field in which he carried out his experiment) and covered them with soil to create wicking hills.

Notes in Hindsight

Lou found he could use a rotary plow to push soil into hills, but his rocky soils made using the tool a challenge. It would buck every time he hit a large stone. While he was able to make it work, he warns that this may not be an ideal tool for rocky soils. This goes to show that what works for one farmer may not work for you. The trick is adapting solutions to the unique limitations and opportunities that your farm offers. That is precisely what the problem-solving process is all about.

He also covered several rows on flat ground (no hills) with straw mulch, hilled rows without any wicking materials, and maintained un-hilled flat ground without wicking materials (control). Each of these rows were separated by flat strips of clover. He collected quantitative soil data by sending samples away for laboratory analysis and measured moisture using a handheld moisture meter in each of the experimental rows.

In the end, his data indicated that the rows with wicking materials increased soil moisture during drought conditions, and hilled rows had lower moisture levels during rain events, despite all of the rows having similar mineral soil characteristics. The wicking hills also tended to display higher degrees of soil microbial activity, as measured by a soil respiration test conducted at the Cornell University Soil Health Laboratory. As a result, the crops planted in wicking hills had significantly higher yields compared to the crops planted in flat fields.

Fine-tune actions

(Task F7: page 50)

Lou did not like using oat straw because it was difficult and time-consuming to lay out. Fortunately, observing the sunflowers he grew on his farm gave him another idea. Normally, he cuts down the sunflowers at the end of the growing season, leaving the stalks in the soil. He wondered whether the root systems and dried stalks could serve as a wicking material the following year.

He fired up the rotary plow again and covered the stalks with soil to perform a small-scale test comparing the sunflowers and oat straw. Sure enough, using the sunflowers as the wicking material worked well. As an added bonus, they served several functions simultaneously, including attracting cucumber beetles away from his squash and cucumber plants, as well as providing table ornamentation in his farm restaurant. The crops grown in sunflower wicking hills fared far better than crops grown in flat ground without wicking materials (Figure 7-8). He took photos of the sunflower-based hills, noting that he could see wet patches where the sunflower stalks had been left. Lou is now preparing another rigorous experiment to conclusively demonstrate the benefits of his sunflower wicking hills and fine-tune his approach before applying the technique to all of his fields.

Insights: You, too, can become an innovator/expert problem solver!

- **Read widely:** You never know where inspiration can come from. In this case, Lou found an idea in a scholarly journal article that explicitly mentioned a technology's applicability in developing countries. His knowledge of his farm allowed him to consider how it could fit into a very different kind of system. Innovation often is not necessarily developing a new technology, but using it in a novel location or manner.

FIGURE 7-7: Lou using his rotary plow to make his wicking hills.

Photo courtesy of Lou Lego.

- **Leverage natural ecosystem processes:** Although it may have been simple to install an irrigation system, Lou harnessed natural processes to do the work for him. Furthermore, rather than finding solutions that only offer a single benefit, Lou developed an approach that provided several ecosystem services.
- **Again, observing the farm system is the root of problem solving:** Lou's approach of using mowed sunflower stalks as wicking materials depended on him closely, systematically, and deliberately observing his normal farm operations. In some cases, doing so can detect problems, while in others, it can identify solutions.
- **Quantitative and qualitative data complement one another:** Quantitative data make it very easy to compare treatments directly, while qualitative data help contextualize that information in a more holistic way. Don't feel obligated to limit yourself to one or the other. Both provided Lou with valuable insights and can be used to communicate your findings to others.

FIGURES 7-8 AND 7-9: Carrots grown on flat fields (left) and wicking hills (right).

FIGURE 7-10: Elderberry Pond.

Photo courtesy of Lou Lego.

Background investigation

(Klaas and Mary-Howell Martens, Lakeview Organic Grain)

Farmer Profile: Klaas and Mary-Howell Martens have cultivated grain crops and raised livestock on their 1,400 acre farm in Penn Yann, NY for over twenty years. Klaas is a third generation farmer who used to conventionally cultivate corn and other grains in large-scale monocultures until 1994 when he converted to organic production. They now grow organic grain corn, as well as soy, spelt, barley, wheat, triticale, oats, rye, red kidney beans, cabbage, and hay, which they sell to food wholesalers, restaurants, and organic dairies for feed.

Observe patterns from records and investigate your problem

(Tasks C2-5: page 28)

Several years ago, Klaas observed that his bean yields had declined. Not one to believe in coincidences, he knew that something had to have changed but wasn't sure what it was. Could it have been his introduction of a new bean variety? He went to Carol McNeil, the regional vegetable specialist extension agent, who pointed out that root rot had infested his beans. He brought this up at a New York Certified Organic meeting he was attending, and many other farmers noted similar issues. After reading the limited primary literature on the subject, Klaas approached Dr. George Abawi at Cornell University, who had researched root rot and found that cultivating yellow mustard and buckwheat could reduce soil populations of the pathogenic organisms and nematodes that cause root rot in beans.

Design a trial and allocate necessary time for implementation

(Tasks E5 and F2, pages 43 and 49)

George and Carol helped Klaas design an experiment comparing the ability of different cropping systems to

FIGURE 7-11: **Klaas Martens (left) and his mustard cover crop (right).**

Photos courtesy of Mary-Howell Martens.

minimize root rot damage relative to a control. George established a randomized complete block experiment in a heavily-infested field and applied treatments of different cover crops, including barley, buckwheat, mustard, alfalfa, and clover, to the replicated plots.

Based on this experiment, George and Klaas identified that planting either mustard or buckwheat before beans significantly reduced root damage, confirming that that cover crop mixture reduced the populations of organisms causing root rot. Sure enough, bean yields also increased. Additionally, Klaas was able to harvest and sell the buckwheat (he didn't harvest the mustard because he terminated it before it went to seed), so this solution provided multiple benefits.

Fine-tune actions

(Task F7: page 50)

Klaas ran into the issue of fine-tuning the timing of the new cropping sequence, which deviated from his previous management system. He reverse-engineered his rotations to identify open windows that would allow him to plant these new cover crops. He started with the cash crops he needed to plant and then determined which cover crops could fit into the sequence, ultimately deciding to frost seed mustard before planting beans and later planting a mix of winter barley and buckwheat after the beans were harvested.

Determine your next steps based on results and your whole farm plan

(Tasks F8, G1, and G5: pages 51 - 53)

Furthermore, although Klaas normally planted alfalfa and clover at the end of every rotation to increase the available nitrogen in his soils, George had informed him that these legumes were co-hosts that sustained the root rot pathogens. To address this and further lower root rot prevalence, Klaas decided to sow clover directly before corn, which did not seem to be affected by the root rot. He followed the corn with mustard to ensure the root rot fungus was eliminated from the soil before planting beans. In addition, by alternating between this new rotation and his original one, he was able to disrupt root rot fungus populations while also sufficiently boosting soil nitrogen levels.

FIGURE 7-12: **Klaas seeding pinto beans in the summer sunset.**

Photo courtesy of Mary-Howell Martens.

Notes in Hindsight

Canadian thistle is an invasive weed that is extremely aggressive and difficult to eradicate. It is particularly prevalent in low-lying, moist areas. Completely by chance, while Klaas was experimenting with crop rotations to minimize bean root damage, he noted that Canadian thistle was much less pervasive in fields where buckwheat had previously been cultivated. The buckwheat quickly formed a closed canopy that suppressed the thistle germination and growth. This demonstrated the utility of this crop in addressing both weeds and diseases.

Insights: You, too, can become an innovator/expert problem solver!

- **Extension can be valuable if used correctly:** Klaas believes that farmers are not effectively collaborating with extension agents. Many farmers go to extension agents for quick-fix solutions to problems rather than using extension as a resource that contributes to attempts at problem solving that are integrated into farming operations.
- **Learning how to observe:** "You need to observe [mindfully]. To get the right answer, you need to ask the right question," noted Klaas. Integrate detailed observations of several interacting factors to properly identify problems and diagnose their causes.
- **Use the Socratic Method:** Constantly ask yourself "Why?" to get at the root cause of problems. Mary-Howell Martens has repeatedly mentioned that the health of their crops is contingent upon the health of their soils; one cannot fix the former without addressing the latter. By focusing on ultimate causes, you can find appropriate solutions to pervasive problems rather than fixing individual surface-level symptoms. This may also help reduce inputs, as well, particularly on organic farms that often cannot simply rely on external inputs such as fertilizers, pesticides, and herbicides.
- **Different strokes for different folks:** Klaas tends to rely on his memory to keep note of observations on his farm because he is a visual learner and has a detailed knowledge of his farm. This approach may not be useful for everyone; there are many ways of keeping records, which we describe on page 29; Box 4-1.

CASE STUDY 6

Experimental Design

(Lou and Merby Lego, Elderberry Pond Farm)

Identify problems and changes as they relate to your goals

(Tasks A3 and D9: pages 17 and 38)

Elderberry Pond Farm (see Case Study #4 for background) had been growing cucumbers for years with small amounts of downy mildew, but they were always able to harvest the crop. Things changed in 2008, when the parasite seemed to be particularly aggressive, killing the plants so quickly the entire crop was lost.

Lou did some research online and discovered that North Carolina State University was investigating a new strain of downy mildew that was devastating crops in the South. He initially was ready to stop cultivating cucumbers until Merby, his wife and co-farm manager, pointed out that they were necessary for the farm restaurant. Lou skipped all the way to the "Design Actions" step. When you have a failing crop that is essential to your farming operation, the problem is obvious!

Design a trial based on your expertise and background research

(Tasks E2 and E5, pages 41 and 43)

Downy mildew spreads by airborne spores, so Lou tried using row covers. This delayed infection by a few days, but the cucumber plants still died. Lou did further research on the spores to get to the bottom of things. He discovered they were 1.3 microns in diameter, and he began to think, "I wonder if there is a filter that can capture them?" Indeed, he found that there are hypoallergenic filters for furnaces that are affordable.

Fine-tune and scale up your trials

(Task F7: page 50)

Lou wrote and received a SARE grant to test his idea that furnace filters could be used to capture the spores if the cucumbers were grown under cover. He built a low tunnel with furnace filters to exclude downy mildew

FIGURE 7-13: In his spore-excluding high tunnel

Photo courtesy of Lou Lego.

FIGURE 7-14: **Lou installing filters in his high tunnel.**

spores from the air intake. There were covered (experimental) and uncovered (control) beds. The low tunnel worked perfectly. He didn't lose any experimental plants to downy mildew. The adjacent beds, both uncovered and covered with row cover, were killed by downy mildew infestation.

Determine your next course of action

(Task F7: page 50)

Getting into the low tunnel to harvest was difficult, and Lou was concerned about temperature getting too hot. Lou wanted a larger solution but was concerned about the possibility of contamination. Could a high tunnel work? What about opening the doors—would spores get in? Based on his previous work in clean rooms, he knew that he could create positive air pressure inside a room, so that when a door was open, air flowed out rather than in.

Adaptive management as a cycle of inquiry

(Task G5: page 54)

Lou built a 100 ft x 25 ft high tunnel funded by a larger SARE grant he had written. All air intake passed through 15 furnace filters at one end of the structure. Positive pressure was maintained so that people entering the high tunnel did not introduce outside air into the tunnel. They planted both cucumbers and tomatoes inside, and

FIGURE 7-15: **Lou's high tunnel for cucumbers and tomatoes.**

Photo courtesy of Lou Lego.

Notes in Hindsight

Unlike the previous example in which Lou performed a replicated experiment, this time he did not. Put simply, replicating treatments is frequently not practical on a working farm. The cost and large-scale nature of the solution, prevented him from using replicated plots. However, both approaches involved controls to distinguish the effect of the proposed solutions from natural environmental variability.

the filters had the additional benefit of preventing tomato late blight. This system works well, and Lou continues using it today!

Insights: You, too, can become an innovator/expert problem solver!

- **Baby steps:** Lou strongly believes in small-scale experimentation before implementing a potential solution or improvement on his farm. It's always better to measure twice and cut once to minimize risks associated with changes.
- **Bring in knowledge from other life/work experiences:** It was Lou's work in clean rooms in his pre-farming life that gave him the idea to use positive air pressure. Innovation is born from combining disparate ideas.
- **Be prepared for other domino effects:** In this case, because so many plants were under tunnels, there was an increased need for irrigation. It's helpful to consider your farm as a system that influences and is influenced by external factors.
- **Grants are helpful:** Lou funded this work through external grants. They offer the financial resources to make changes, as well as the validation that an idea is worthwhile and perhaps useful to a broader audience.

Success criteria
(Karma and Michael Glos, Kingbird Farm)

Farmer Profile: Karma, Michael, and Rosemary Glos own and operate Kingbird Farm in Berkshire, NY. They have been certified organic since they began farming commercially twenty years ago. While they sell houseplants, herbs, and vegetables that they grow in a one-acre market garden and greenhouses, about half of their sales are meat and eggs from their grass-fed Scottish Highland Red Angus beef cattle, pigs, chickens, and ducks. In addition to these animals, the Glos family also has two draft horses that help with tilling fields, spreading compost, logging, and all the heavy pulling on the farm. In addition to the crops and livestock, they harvest wild foods, such as ramps, mushrooms, and fiddlehead ferns, from the 80 acres of forest that cover a majority of their property. They sell all of these farm products at the Ithaca Farmers Market, a local cooperative grocery, and a 24-hour self-serve farm store on their property. Karma has shared her work at a Northeast Organic Farming Association (NOFA) conference and written articles for the NOFA newsletter.

Having a concrete farm vision can help identify and solve problems

(Task A4: page 18)

When they started farming, Karma and Michael knew they wanted to raise all organic livestock in a self-sufficient manner. Because they bred their own pigs and cows, these would not be a problem, but organic chicks and ducklings were not available for purchase at the time. Despite an extensive search, they could only find birds raised on non-GMO feed. Although organic chickens and ducks are not required to be raised from organic chicks, the Gloses did not want to give up on their vision for the farm and had to find another solution that wouldn't be prohibitively expensive. They decided to breed their own organic chicks and ducklings.

FIGURE 7-16: The Glos' organic chicken flock.

Photo courtesy of Karma Glos.

FIGURE 7-17: Karma Glos

Photo courtesy of Karma Glos.

Identify challenges & opportunities

(Task D9: page 38)

They first had to identify breeds that would suit the needs of their farm. They were able to easily purchase pure-bred Pekin ducks from a hatchery, raise them organically, and breed them within the flock. Chickens, however, presented a more complicated challenge. Karma considered using heritage dual-purpose birds, but they developed too slowly to be financially viable. Most commercially available meat birds were hybrids bred to be terminal stock. As a result, they were too big to breed. Karma was concerned that the roosters would be too big and might hurt the hens. Even if they managed to breed, they weren't sure whether the hens would lay fertilized eggs or produce viable offspring.

Fine-tune the next course of action and continuous adaptation

(Tasks F7 and G5: pages 50 and 53)

Given these constraints, the Gloses tried to dehybridize a free-range meat breed. They purchased chicks and selected birds that grew slower than the average broiler and could walk well at maturity. They then bred these birds within their own flock over several generations. "There was quite a learning curve to figure out hatching," Karma recalls. They had to fine-tune their management practices to balance tradeoffs between egg production and meat quality. After several seasons of selective breeding, they managed to establish a "breed" that grew fast and big enough to be economically viable, but not so fast and big that they were unable to breed at sexual maturity. The farmers' reward was a red broiler-type chicken that matured in 10–12 weeks but could still breed for one season.

Success criteria are in the eye of the beholder

(Task F8: page 51)

Raising their own organic chicks costs Kingbird Farm about $4.50/bird, which is more expensive and time-consuming than simply buying chicks and raising them organically. Regardless, Karma sees this additional cost as worthwhile. "In the end, I am producing something that doesn't exist. There's nothing to compare it to. Is that success? It doesn't maximize profits, but is it more sustainable? Probably." She also appreciates the autonomy of having things fully in her control.

Insights: You, too, can become an innovator/expert problem solver!

- **Having a strong vision for your farm can help clarify which solution is acceptable:** Given that Karma and Michael had a farm vision focused on avoiding conventional agricultural crops/products, they decided to go ahead with dehybridizing their chicken breeding stock, despite it being a costly and difficult task.
- **Evaluating the results of your efforts as successful or not depends on your goals:** Every decision has costs and benefits, but their importance (or even whether they are considered costs or benefits) varies from person to person. The Gloses see the high costs of raising organic chicken breeding stock as being worth the additional effort and reduced profits.
- **While it can sometimes be helpful to have an established and systematic plan to evaluate particular management strategies, in many circumstances this is neither practical nor necessary:** Feel free to experiment with management by changing things as you go along—just make sure to have some way of documenting your decisions and how you evaluate their outcomes.
- **Diversity is valuable:** Kingbird Farm has many streams of income, so Karma and Michael can make up for any additional costs associated with raising their own chicks organically by reducing other costs or increasing production.

Evaluating results
(Chaw Chang and Lucy Garrison, Stick & Stone Farm)

Farmer Profile: Chaw began renting a few acres in Ithaca, NY, back in 1996, but Stick & Stone Farm has grown to 72 acres in the subsequent twenty years. Chaw and Lucy Garrison–his partner in both life and farming–devote about half of their property to growing a wide variety of certified organic vegetables and fruits, including several types of Asian produce such as kohlrabi, Asian greens, and daikon. They sell a majority of their produce wholesale to local groceries and restaurants, as well as through a community-supported agriculture program.

Identify the problem and convert it into an opportunity
(Task D9: page 38)

Chaw had never been fully satisfied with the way he managed the aisles between the raised beds he used to grow organic vegetables. The beds were not permanent, so the spacing between them varied. He had some success removing weeds with a spider cultivator, but found it left bare ground that contributed to soil erosion, so he sought out an alternative that wouldn't leave behind bare ground.

Fine-tune actions and continuous adaptation
(Task F7: page 50)

After discussions with other farmers, Chaw tried to use a living mulch to minimize erosion after removing weeds between his raised beds. At first, he tried hand-broadcasting rye seed after tilling, but this was time-intensive. Although it reduced erosion and suppressed weeds, the seed also spread into the beds where it competed with vegetable and fruit crops.

To streamline the process and focus the seed distribution in the aisles, Chaw mounted a broadcast spreader to the spider cultivator, allowing him to remove weeds and sow rye in one pass. However, this solution was also unsatisfactory. The spider cultivator did not effectively cultivate the wheel tracks, and the broadcast spreader did not spread the seeds over the entirety of the aisle. To address this, Chaw purchased replacements: a hillside cultivator and two Gandy boxes.

Review success criteria when solutions becomes problems
(Task F8: page 51)

While using rye as a living mulch suppressed weeds and minimized erosion in his aisles, it created a new set of problems Chaw had not initially foreseen. The rye needed to be mowed, requiring him to purchase a mower, which needed to be repaired several times. Only after buying the mower did he realize just how much mowing living mulches encouraged the establishment of annual grassy weeds. Chaw found it difficult to set aside a sufficient amount of time to mow frequently enough to prevent the grasses from going to seed.

FIGURE 7-18: Chaw, getting ready to seed his vegetables in the spring.

Photo courtesy of Sue Henninger/Tompkins Weekly.

Determine the next course of action by reassessing costs and benefits
(Tasks G3 and G5: page 53)

Chaw realized that mowing living mulches was a far more labor-intensive process than using a tractor cultivation, but he could change when he planted his

mulch to reduce this time commitment. Instead of establishing a living mulch early in the growing season, Chaw tries to cultivate his tractor tire tracks two-to-three times prior to planting a mulch, and then plants a cover crop on the last cultivation. This eliminates weed pressure in the tractor's tire tracks and reduces the number of times the row tracks need mowing.

Alternatively, he also uses hay and straw mulch in the aisles between his raised vegetable beds. While mulching by tractor is more time consuming than cultivating, it offers benefits, including the addition of organic matter to the soil, and it only needs to be done once a year. Furthermore, using hay/straw mulch is better for longer season crops such as fruiting annuals, particularly cucurbits and nightshades, and where row covers are used. Introducing weeds along with the mulch can be a potential problem, but Chaw feels that these downsides can be limited by purchasing hay that was cut at the proper time and using older hay to reduce weed seed viability.

Insights: You, too, can become an innovator/expert problem solver!

- **Know when enough is enough:** Many complex problems will reveal new challenges. On-farm problem solving and research is a repetitive process, and positive results may only come after long time-lags or initial failures that help you better understand the nature of the problem and the farm function. Clearly establishing a farm vision can help you know when to stop sinking time and resources into addressing problems that aren't critical.
- **Establish clear metrics of success:** Chaw identified several variables that he used to evaluate whether different management strategies improved upon past attempts, including harvest time and yield. Establish these at the onset of your efforts so different treatments can be compared consistently.
- **Listen to your employees:** Chaw's farm crew records what they do on a daily basis to complement his observations of the farm. Having more eyes is particularly helpful in managing larger areas, and the individuals directly managing a particular location often have the best understanding of potential problems and solutions.
- **Get to know your farm:** Chaw and Lucy walk the farm on a weekly basis, occasionally with their workers. This facilitates communication between members of the team and can open one's eyes to alternate perspectives while also helping develop a deep and detailed understanding of the functions and characteristics of the farm.

CASE STUDY 9

Invite feedback from collaborators
(Harold Schrock, Berry Hill Farm)

Farmer Profile: As a teenager, Harold was given charge of his father's farm back in southcentral Indiana. He learned how to run the farm through a combination of trial and error, short courses on regenerative agriculture, and help from other farmers. His family later sold this farm and purchased over 200 acres in Central New York, where Harold raises a combination of grass-fed beef, long-term perennial forage, and short-term organic row cash crops. This farm business is focused on wholesale beef marketing and raising cash crops for organic dairies.

Network with farmers and consult with experts
(Tasks A1 and D8: pages 16 and 37)

Harold participated in a project organized by a seed company, which approached him to evaluate the effects of several of their cover crop mixes. Although Harold was satisfied with the cover crop mixture he had been using, he was always on the lookout for ways to improve his soil health and lower input costs, including alternative cover crop mixes appropriate for his farm.

Design a trial and collect resources
(Tasks E5 and F1: pages 43 and 49)

Harold evaluated 10 cover crops (eight of which were commercial mixtures provided by the seed company) and a control. Although the company determined which mixtures he would be testing, he decided on the location, layout, and management of the field trials. Conveniently, Harold had a whole field that had been

FIGURE 7-19: Harold's cover crop test strips.

Photo courtesy of Harold Schrock.

Notes in Hindsight

Each of the farmers in this study managed a single replication with a control. This collaboration allowed them to evaluate how the different cover crop mixtures performed across different growing conditions. However, more within-farm replications would be necessary to evaluate how the mixtures would perform under the varying conditions across any individual farmer's fields.

previously planted with small grains and was due for cover cropping, so he decided to use it for the experiment. He also chose this site because it was close to a road for easy access. The size of the field allowed him to plant different treatments in 20 x 300-foot strips that corresponded with the width of his equipment.

Execute a plan and observe results

(Tasks F4 and G1: pages 49 and 52)

Harold planted the cover crops in the early fall and spring before using a speed disc to till them under. Next, he planted corn and measured its yields in the fall to compare the effects of the different cover crop mixtures.

Consult and collaborate with others

(Task F3: page 50)

The seed company that organized this study also replicated the trial by collaborating with several other farmers in New York and Pennsylvania. Most of the other farmers only planted small plots and evaluated cover crop vigor, but they were able to collectively evaluate the cover crop mixtures' performance in a wide range of environmental conditions.

Insights: You, too, can become an innovator/expert problem solver!

- **Divide and conquer:** Especially if several of your neighbors are having the same problem, it may be beneficial to collaborate with them in developing a solution. This will reduce your individual effort, and you'll need to allocate less space to the experiment.
- **Find resources wherever you can:** Harold received funding for this effort from industry. However, you can also receive grants from extension agencies and universities. Writing an application may be time-consuming, but this can actually help with the experiment itself, as it forces you to have a clearly defined experimental procedure.
- **Multiple measures or single indicators:** In this case, Harold and the other farmers were most interested in the effects of these cover crop combinations on grain production. This is an indirect proxy indicator for other factors, like weed populations and soil quality. While yield is an important consideration, it may be more appropriate to measure several variables directly. This depends on the resources available to you and your intentions.

CASE STUDY 10

Reinventing a whole farm system
(Adam and Courtney Squire, Unbound Glory Homestead)

Farmer Profile: Adam and Courtney Squire farm a diverse mix of heirloom vegetables in their 15.4-acre market garden. They offer a farm share/CSA and also sell their farm products at a number of local farmers' markets. Being a smaller farm, they recognized the need to provide additional value to their customers, which they accomplished by maintaining an email listserv for communicating what produce future CSA shares will contain and offering meal ideas. Adam and Courtney also steward a small apiary for the honey and pollination services the bees provide.

Identify your farm vision and values with the help of experts
(Tasks A3-4: page 17)

Adam and Courtney had wanted to manage an organic farm and contribute towards building a sustainable food system for many years, so they purchased a piece of land that had been previously managed as part of a conventional dairy farm. At first, their goals were to reduce inputs and environmental impacts, but they quickly realized that they didn't want to just be "less bad"; they wanted to become "more good" by restoring their farm's ecological function as an integral part of the landscape.

Review your production systems
(Task B4: page 25)

Adam and Courtney had their work cut out for them. The property had a long history of continuous corn and hay cultivation, which resulted in soil compaction, high phosphorus from manuring, and low micronutrient levels. They reached out to the Natural Resource Conservation Service (NRCS), who sent a conservation specialist to audit the farm and establish a conservation plan. He pointed out several areas where sheet and rill erosion were washing away soil, dug a soil pit to demonstrate the soil crusting and compaction, and noted the low earthworm populations to illustrate the lack of soil biota. The NRCS specialist suggested they focus on developing soil health by transitioning towards no-till production.

Research solutions and talk to experts
(Task D8: page 37)

The Squires spent the following winter educating themselves about soil health, regenerative agriculture, and no-till farming. They used a range of resources, including books, extension workshops, online lectures on YouTube, and extension manuals. Adam cites other no-till farmers, like Bryan O'Hara at Tobacco Hill Farm, as sources of inspiration and information. As a result of their research, the Squires identified several practices they expected would help improve their farm's soil health, including cultivating cover crops and applying carbonaceous mulches.

FIGURE 7-20: Adam inspecting his cover crop performance.

Photo courtesy of Courtney Squire.

Plan and execute a trial

(Task F4: page 49)

That spring, Adam and Courtney tilled their field one last time and added compost to inoculate the soils with a diverse microbiome. They then tried planting a variety of cover crop blends that Adam mixed himself. This granted him a greater degree of control over the species composition, which he manipulated to meet his criteria for success: establishing diversity, increasing density, and providing multiple stacked functions (e.g., legumes for nitrogen fixation, grasses to increase soil carbon, and brassicas that broke up compacted soils). They planted each of these different cover crop mixes in different beds within a single field. They also experimented with different carbonaceous mulches, including aged woodchips, rye straw, and leaves during that first year. Again, they applied these treatments to different beds in the same field, minimizing background environmental variability and allowing for easy comparison. At the end of the season, they measured and compared the cover crops' and mulches' effects on soil fertility using soil tests, compaction using a penetrometer, and soil respiration using a Solvita test.

Notes in Hindsight

Although the Squires performed some trials, they dove right into applying other management strategies on their entire farm, in part because they could rely on the income from Courtney's day job at Whole Foods to make up for any financial losses, but also because they felt that the small size of their farm prevented them from devoting much area to testing multiple solutions. Although this is a valid concern, other small farmers may not have the benefit of alternate sources of income, making it all the more important that they establish small-scale trials that evaluate changes relative to a control before trying any of the changes at the whole farm level. Furthermore, increasing resilience by maintaining diversity within and among production systems can increase your resilience to failures, which are always a possibility when overhauling your whole farm management plan.

Fine-tune actions in response to lessons learned during experimentation

(Task F7: page 50)

Although only two years have gone by, the Squires have observed noticeable changes in their soil health. In some cases, the vigor of the soil ecosystem bounced back so quickly and drastically that they are adjusting their practices to slow down decomposition and nutrient cycling. For instance, they noticed that rye mulch breaks down too quickly, leaving exposed soil, so they are replacing it with sorghum sudangrass mulch, which has a higher carbon-to-nitrogen ratio.

Insights: You, too, can become an innovator/expert problem solver!

- **Working is observing:** Adam is always actively making observations while he is working in his fields and generally depends on his memory to keep track of them. This works well for him, in part given the small size of his farm, but keeping written records becomes increasingly relevant as the size of your operation increases.
- **Listen to what your farm is trying to say:** Adam reminded us that weeds and pests are often the farm system trying to communicate that something is amiss. However, be knowledgeable about the key ecological tenants and interactions upon which your farm functions to understand these messages. For example, the presence of certain weeds could be a function of soil nutrient deficiency, which may, in turn, be caused by an imbalance in the soil microbiota community.
- **Holistic solutions to wicked problems:** Wicked problems are not easily solved. Many times, solutions to initial problems cause additional, unforeseen issues. These offshoot, superficial problems are often symptomatic of deeper issues. In the case of Unbound Glory Homestead, improving soil function was fundamental to addressing the other production problems the Squires faced. They shifted their focus from the health of their crops to the health of the system as a whole by encouraging diversity, intermediate disturbance, and vitality.
- **Sometimes that which matters most is invisible to the eye:** Adam distinctly remembers that one indicator he used to assess soil health was smell; initially his soils had no odor, but now they emit the rich earthy aroma of geosmin, a volatile compound released by certain bacteria. Quantifiable measures of success are important for meeting goals, but don't discount qualitative or aesthetic variables.

CASE STUDY 11

Developing an innovative farming system

(Steve Groff, Cedar Meadow Farm)

Farmer Profile: Steve Groff has always wanted to become a farmer like his father and grandfather before him. Early in his career as a farmer, Steve recognized the value of cover crops, which he integrated into his farm system in the mid-90s. He and his family currently farm 305 acres. Most of his cultivated farm area is devoted to cash grain crops like corn, soybeans, and small grains, but he also grows several acres of pumpkins and high tunnel tomatoes, as well. He has always been excited to try out new ideas and has translated that into several innovations, two of which are described here.

Galvanized by the massive gully erosion he observed in his fields, Steve Groff converted to no-till farming in the 1980s and never looked back. Since then, he has been consistently fine-tuning his farm system to improve soil health and reduce herbicide inputs over decades of repetitive problem-solving cycles and developing innovations when no readily available solutions could be found.

Benefits of collaboration

(Task D8: page 37)

Steve collaborated with Dr. Ray Weil at the University of Maryland for over 12 years to assess effects of his farm management on soil health over time. This fruitful research relationship began in 1996, when they collaborated to evaluate soil health in different farming systems. Working with a researcher and his team helped Steve collect and analyze data for a wide variety of variables, including soil organic matter, aggregate stability, nutrient levels, crop yields, microbial biomass, and weed populations. This would have been difficult if he had attempted to tackle a project of this magnitude alone. Furthermore, Ray taught Steve the experimental methods he still uses to this day. Before their work together, Steve knew little about the experimental designs that have become so central to his problem-solving process. Finally, Ray introduced Steve to a number of new technologies and management strategies to which he may not have been otherwise exposed. For example, they tested and developed the tillage radish together, which Steve wound up marketing as a multifunctional cover crop.

FIGURE 7-21: Steve and his tillage radish.

Photo courtesy of Jan Murphy of PennLive.com.

Identify opportunities

(Task D9: page 38)

Steve is always seeking out opportunities to improve his farm system. "I'm looking for surprises. I can wake up every morning wondering what I'll discover today," he remarked. Sometimes he uncovers these surprises through his background research. He consistently reads books, academic research articles, and extension reports. He also gets ideas from other farmers; he's always excited to discuss the problems others are having, as well as the solutions they're trying. For instance, he was inspired to develop his roller-crimper as a result of Brazilian research he heard about at the National No-Till Conference.

Prioritize innovation

(Task D9: page 38)

Of course, when you're bombarded with new ideas every day and have limited resources to evaluate them, it is important to have a way of prioritizing your focus. Steve begins by asking himself how the change would affect the health of his farm overall. Being preoccupied

FIGURE 7-22: Steve and his roller-crimper in action.

Photo courtesy of Steve Groff.

with superficial symptoms as opposed to addressing ultimate drivers of a process has limited benefit. He also considers the logistical challenges involved in conducting a trial. How much time, money, and effort will need to go into conducting a trial, and how does that compare with the benefit it provides? Although this is partially a financial cost–benefit question, other qualitative factors fit into the equation too. Steve is also concerned whether and how his experimentation will benefit other farmers.

Finally, although proactive innovation is a worthwhile pursuit, one can be too forward-thinking. Steve asks himself whether the change or innovation will be realistically adopted. For example, Steve tried cultivating hemp in the late 90s, but there wasn't a market for the product. Now, however, hemp has become increasingly popular, so he is ready to give it another go. All of these factors inform his decision to pursue a project.

Initial small-scale trials

(Task E2: page 41)

If a particular product or management change appears relevant, timely, and beneficial, Steve will evaluate it using a side-by-side trial. This involves an unreplicated, uncontrolled test of different variants of the same approach, allowing him to determine whether this is something he wants to devote further resources to pursuing. Steve urges farmers interested in evaluating innovative changes to their farm system to begin at a manageable scale, gain experience, and then fine-tune and scale up their tests.

Scale up experimental approaches

(Task E5: page 43)

If the side-by-side trial shows promise, Steve scales up his experiment and conducts a more rigorous study. The specific methods he uses depends on the nature of the innovation he is testing, as well as the resources he has available, but these experiments tend to be randomized, replicated, and controlled. He will divide up a field and apply treatments to different experimental units (usually a row to ease management). However, Steve isn't satisfied with a single year's worth of data. He tries to repeat the experiment for two or three years to ensure that his results are consistent and not a fluke.

Collect resources and delegate tasks

(Task F1: page 49)

To facilitate his systematic process of experimentation, Steve often delegates tasks to his workers. As a result, he tends to adopt a managerial role of developing ideas, deciding what to tackle next, assigning duties, and disseminating results. Steve is also a proponent of using

FIGURE 7-23: **One of Steve's many replicated cover crop trials.**

Photo courtesy of Steve Groff.

technology to collect and organize data. His equipment can monitor a wide array of variables, including yields, fertilizer application, and seeding rates, among others, and he uses Excel spreadsheets to keep track of all of these data over multiple years and multiple cycles of innovation.

Insights: You, too, can become an innovator/expert problem solver!

- **Know your goals to find a solution:** Steve underscored the need to pair concrete objectives with specific methods for achieving them. You need to be strategic rather than just making random changes in the hopes one of them might work. This requires you to also understand the ecological processes and principles at play, at least to some degree. Having a technical advisor can help in that regard.
- **Plans are useless, but planning is essential:** Steve sketches out his farm management plan, including his innovations and experimentation, about 12 months in advance. This gives him time to prepare equipment, acquire the necessary resources, and do his background research. However, Steve also notes that there is no formula for success. There will always be unanticipated pitfalls that need to be addressed on the fly when evaluating a new practice. Innovators need to be adaptive and recognize that failure is also a learning opportunity.
- **Start small and work your way up:** Steve cautions farmers against being cavalier, even if they do their homework. When applying new farming methods, limit your initial attempts to the number of acres you can afford to lose. Assume the worst, and keep your mistakes small. It's better to gradually scale up your experimentation over several years than pursue an untested solution down a blind alley that may very well be a dead end.
- **Commit and devote resources to experimentation:** Natural processes take time. Steve urges farmers to keep trying and stick to their experiments even if they aren't getting the results they want. As a rule of thumb, Steve devotes 10% of his time to experimentation. He also reminded us that while the general principles of good farm management are applicable around the world, the details need to be worked out at the local level. What works on other farms may not work on your farm, or even in different fields within your farm. To ensure he stays on the cutting edge, Steve devotes a certain acreage of his farm to experimentation every year.

8 Appendices

Appendix I: Established farmer networks and agricultural organizations

Name	Description
Conferences and Other Organizations	
Northeast Organic Farming Association	A group organizing regional and state meetings to promote the production of local organic food and farming systems
Pennsylvania Association of Sustainable Agriculture	A community of farmers focused on education and research regarding agriculture in Pennsylvania and the Middle Atlantic States
Sustainable Agriculture Research & Education	An extension organization focused on promoting productive and sustainable American agriculture
The Grassfed Exchange	A conference for regenerative and sustainable food producers
Organic Produce Summit	A network with organic growers, distributors, processors, and retailers
Farming for the Future Conference	A conference featuring workshops, presentations, and discussions for farmers, educators, and professionals
Ecological Farming Association	An organization facilitating the development of ecologically and socioeconomically sustainable food systems through education, networking, and advocacy
Farmer-to-Farmer Networks	
Southern Sustainable Agriculture Working Group	A partnership of farmers across 13 southern states striving to develop a sustainable farming and food system
Appalachian Sustainable Agriculture Partnership	An organization focused on connecting farmers and markets to build healthy communities tied together by food
Northeast Beginning Farmer Learning Network	A network of farmers who have been operating for fewer than 10 years in the Northeastern United States to facilitate sharing events, information, and professional development opportunities
Young Farmer Network	A network connecting all farmers to facilitate cooperation and collaboration to improve the resilience of local food systems and economies
Sustainable Farming Association Farmer-to-farmer Network	An organization dedicated to facilitating communication, programs, and events among farmers focused on improving the sustainability of agricultural practices
Women Food & Ag Network	A network encouraging women to develop an ecologically sound and socio-economically just agricultural and food system through programs and resource sharing
National Young Farmers Coalition	A political advocacy organization that represents and organizes young farmers and provides them with resources for success

Appendix II: Sample resource inventory worksheet[1]

Soil Resources								
Soil Type	Percent Organic Matter	pH	Nitrogen	Phosphorus	Potassium	Magnesium	Calcium	Cation exchange capacity

Land Resources			
Land cover/use	Value ($)	Acres	Own/rent

Water Resources			
Water source	Value/avoided irrigation costs ($)	Quality	Quantity (flow/volume)

Equipment Resources				
Item	Cost ($)	Quantity	Condition	Own/rent

Infrastructure Resources				
Item	Value ($)	Quantity	Condition	Own/rent

Human Resources			
Name	Jobs/services performed	Skills	Time available

Financial Resources							
Liquid capital	Asset:debt ratio	Solvency	Equity:asset ratio	Debt:equity ratio	Investment	Current Quantity	Mature quantity

[1] Adapted from Huelsman, M. F. (2008). Organic Whole Farm Planning Workbook. Ohio Agricultural Research and Development Center of The Ohio State University.

Appendix III: Grants for farmer experimentation

How-to guides

- Doye D, Siems S Funding for Small-Scale Farms: Tips for Grant and Loan Proposals. Oklahoma Cooperative Extension Services, Stillwater, OK.
- Krome M, Reistad G (2014). Building Sustainable Farms, Ranches, and Communities: A Guide to Federal Programs for Sustainable Agriculture, Forestry, Entrepreneurship, Conservation, Food Systems, and Community Development. United States Department of Agriculture, Washington, D.C.
- USDA (2015) Organic Resource Guide: Your guide to organic and organic related USDA programs. United States Department of Agriculture, Washington D.C.
- USDA (2017) Growing Opportunity: A guide to USDA sustainable farming programs. National Sustainable Agriculture Coalition, Washington D.C.
- NE SARE (2018) Farmer Grant Application Instructions. Sustainable Agriculture Research and Education Program, South Burlington, VT.
- NE SARE (2018) Guide for Northeast SARE Farmer Grant Technical Advisors. Sustainable Agriculture Research and Education Program, South Burlington, VT.

Available grants

United States Department for Agriculture (USDA)

- Sustainable Agriculture Research and Education (SARE) Farmer/Rancher Grant Program: Funds farmers' efforts to develop and disseminate new products and practices through field trials, demonstrations, and other experimental designs
- Federal State Marketing Improvement Program (FSMIP): Provides matching funding to help farmers explore and exploit new markets for agricultural products
- Specialty Crop Block Grant Program (SCBGP): Offers funding to improve specialty crop productivity and quality

Natural Resource Conservation Service (NRCS)

- Environmental Quality Incentive Program (EQIP): Provides agricultural producers with the financial resources and support needed to meet their production goals, address challenges, and pursue best practices that support conservation efforts
- Conservation Stewardship Program (CSP): Helps land managers develop a conservation plan that is tailored to their property. Aims to increase crop yields and improve grazing conditions while simultaneously ensuring ecosystem health and wildlife habitat
- Agricultural Management Assistance (AMA) Program: Provides financial and technical assistance to farmers for reducing environmental impacts such as runoff contamination, water use, and erosion

Search engines and listings

- Sustainable Agriculture Research and Education Program
- BeginningFarmers.org
- Grants.gov
- National Institute of Food and Agriculture

Appendix IV: Personal weather stations

As personal weather stations have become increasingly affordable and accurate, you no longer, "need a weatherman to know which way the wind blows." Personal weather stations offer more detailed, up-to-date information about local weather conditions to complement regional forecasts, thereby informing experimental management and helping to contextualize results. There are several factors to consider when deciding on which personal weather station to purchase:

- **Type of data:** Basic models will collect air temperature, precipitation, humidity, and wind speed, but more advanced stations can also monitor a range of variables for specialized purposes, including soil moisture and temperature, UV incidence, and many more. Be sure to identify a station that will collect the data you need.
- **Connection type:** Weather stations transmit data from the station to your computer via cables or a wireless Wi-Fi connection. While wireless stations are convenient and easier to install, their signals can sometimes be finicky and unreliable. It's also important to evaluate whether the maximum transmission distance (which ranges from 330 to 1,000 ft.) is long enough to reach your home.
- **Power source:** Weather stations can be AC-, solar-, or battery-powered. Each of these power sources have their strengths and weaknesses. AC is generally the most reliable but most difficult to install; solar- and battery-powered units require little in the way of setup but can sporadically lose power.
- **Accuracy:** Although it isn't a hard-and-fast rule, the accuracy of readings is often related to cost; the cheaper the unit, the less accurate it is.
- **Update frequency/data density:** Many stations collect updated measurements at regular intervals. Although getting more data can help you draw more accurate conclusions about trends, it can be difficult to manage large amounts of data. One or two data points per day is sufficient for most agricultural applications. Try to find a model that allows you to edit the frequency of data collection or, better yet, presents averages over the entire day.
- **Data management:** The more automated the data collection process is, the easier it is to collect information and the more likely you are to use it. Cheaper models will require you to manually record the observations, so it may be worth the cost to purchase a model that allows you to wirelessly download the data to your computer.
- **Expandability:** You may outgrow a beginner basic station and want to measure additional or different variables. Some stations can't be upgraded, which will require you to buy a whole new station. Others allow you to purchase cheaper monitors that measure individual variables so you can pick and choose which you want.
- **Durability:** Weather stations have to weather the weather. Choose stations that are made of rugged materials and have a casing for sensors and gaskets to prevent moisture from entering the equipment. User reviews can also be informative.
- **Internet/Wunderground connectivity:** If you select a sufficiently precise wireless model that can forward data to your computer and mobile device, you can also choose to contribute data to Wunderground and improve the precision of their local forecasts.

Installing your personal weather station

We won't go so far as recommend specific models, as there are too many that may very well be outdated within a few years. However, Davis, Ambient, AcuRite, and La Crosse are well-regarded brands.

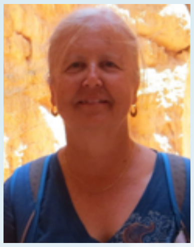
Once you select which model is right for you, be careful about where you install it. Wunderground offers several guidelines for installing your personal weather station, which we summarize below:

- Locate your station at least five feet away from any trees or overhanging roofs, which can influence precipitation readings.
- Don't place your station in poorly ventilated alleyways or walled-off areas, which will influence wind speed and temperature readings.
- Keep sensors at least 50 feet from paved surfaces, trees, or water bodies to ensure the accuracy of temperature and humidity measurements.
- Locate the station away from tall objects at a distance four times their height to ensure the station isn't in their shadow.
- Use a radiation shield to protect your temperature sensor from direct sunlight.
- Make sure your temperature sensors are at least five feet above the ground and your wind sensor is 7–30 feet above the ground. Flagpoles and fence posts are often good sites.
- Find a location that is close enough to your house that the station can transmit data wirelessly.

Problem Solving and Innovation on the Farm
A How-To Manual

This manual will help you improve your farm by combining problem solving and experimentation with day-to-day farm management. The step-by-step process outlined here is based on the know-how of experienced farmers who have developed innovative approaches for adapting their farms to changes. By explaining the techniques these farmer innovators use, this manual will teach you how to successfully identify research questions, test alternative solutions, and collect data for yourself.

About the Authors



Laurie Drinkwater is a professor in the School of Integrative Plant Science at Cornell University. Her research focuses how soil nutrient cycles are controlled by plants and soil microbes in agroecosystems. She carries out extension and outreach activities in addition to research that actively involves farmer participation.

Tomasz Falkowski is a postdoctoral researcher focused on documenting farmer-driven forms of inquiry and problem solving. His graduate work involved interdisciplinary and international collaborations with scientists, NGOs, and smallholder farmers in Mexico to identify how agroecology could be integrated into restoration projects.

"[This] is a valuable tool for new and experienced farmers to explore the decision making processes of a variety of farms."
–Karma Glos (Kingbird Farm, Berkshire, NY)

"I believe the manual will be valuable for new farmers starting out facing new problems like climate change. I wish we had had something like this when we started."
–Lou Lego (Elderberry Pond Farm, Auburn, NY)

"Forty years ago, these ideas in this document would have been invaluable to me as I designed and developed my farm."
–Mike Kane (Shamrock Hill Farm, Port Crane, NY)

DACUM panel participants

Jody Bolluyt
(photo courtesy of John Carl D'Annibale / Times Union)

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