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SARE Sustainable Agriculture Research & Education

Cultivating Climate Resilience on Farms and Ranches

Sue and Gary Price are taking steps to improve the resilience of their Texas ranch to the hotter, drier conditions they have seen in recent years. *– Photo by Karl Wolfshohl*

GARY PRICE, WHO HAS PRODUCED CATTLE NEAR Blooming Grove, Texas, for more than 40 years, knows something about the weather. According to him, the weather used to follow a fairly predictable pattern. "We had cold winters and then a good spring flush," he said. "We knew when our clovers were going to start growing and could almost predict to the day when we were going to have enough grass to stop feeding. If you could hang on until mid-September, when the fall rains would start, you'd be okay."

Since about 2007, however, Price has seen a new kind of variability to the weather. Heat waves have been longer and more intense, and droughts have been more persistent, including a three-month stretch with no rain in 2011 that left all of his ponds dry.

Price is not alone in grappling with more variable weather patterns and extreme weather events. Farmers and ranchers throughout the United States have been experiencing changes in weather over the last two decades that make it harder to produce crops and livestock.

In the Midwest and Northeast, more frequent heavy spring rainfalls complicate fieldwork and bring catastrophic flooding. In the Southwest, prolonged and extreme droughts have forced many ranchers to reduce herd size or exit ranching altogether. As winters warm and growing seasons lengthen, pest populations are increasing throughout the country. Warmer winters and springs cause fruit trees to bloom earlier, increasing the risk of total fruit crop failure due to freezes. In many regions, producers struggle to manage more periods of higher temperatures and dry weather, along with more heat waves and drought. This situation is made more challenging as competition for water intensifies.

Even without these kinds of changes in the weather, agriculture is a risky business. The outcome of every

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Many of the best practices for addressing climate risk are commonly associated with sustainable agriculture, such as using cover crops to improve soil health. Here, rye is growing in corn stubble on a Maryland farm.
– Photo by Edwin Remsberg

growing season hinges on dynamic interactions between soils, crops, livestock, pests, weather, finances, regulations and markets. Year after year, farmers and ranchers do their best to manage for these sometimes unpredictable risks inherent to their profession.

But in recent years, managing weather-related risk, already one of the highest risk factors in agriculture, has become even harder, as weather patterns become more variable from day to day and season to season.

These changes in weather patterns have created a new kind of risk that is expected to grow in importance in coming years. This new kind of risk, called *climate risk*, is defined as the additional risk created by rising temperatures and more variable precipitation patterns associated with changing climate conditions.[1]

The good news is that many of the best strategies for addressing climate risk are already familiar to farmers and ranchers through practices commonly associated with sustainable agriculture, such as diversifying crops, livestock, enterprises and markets; improving soil health through cover crops, no-till, composting and other techniques; integrating crops and livestock; adopting management-intensive grazing; reducing the use of off-farm inputs; and using whole-farm planning.

Price, for example, weathered the drought in 2011–2012 because of changes he had made to his farm early on: planned grazing to restore degraded soils and native tallgrass prairies throughout his ranch; reducing his herd size to about 85 percent of what he knew his land could support; and leasing additional rangeland to provide some forage reserves in the event that extreme weather reduces forage yields. He is now experimenting with grazing cover crop cocktails on his cropland. "We're learning to manage for less water … and more heat, so we're keeping as much cover as we possibly can on the land and then trying to balance that out with our stock numbers," he said.

As these changes make Price's ranch more sustainable, they also make it *resilient,* a key concept and strategy to help manage the new risks posed by changing weather patterns.

A resilient agricultural operation is one that is diverse, healthy, flexible and self-reliant. When confronted with changing weather patterns or an extreme

Using Sustainable Agriculture Principles to Manage Climate Risk

Sustainable agriculture and agroecology, the science of sustainable food systems, provide a strong foundation upon which to build a resilient U.S. agriculture. A rich knowledge base of practical application and innovation informed by a deep understanding of the ecology of agriculture can be used to guide the development of locally adapted, sustainable and climate-resilient systems. Over the last 40 years, farmers, ranchers and others committed to sustainable food systems have worked together to develop and share information about agricultural sustainability through both formal and informal research, teaching and learning networks. This accumulated knowledge provides a wealth of potential adaptations, well-tempered by practical, place-based experience, that you can use to enhance the climate resilience of your farm or ranch.

Key sustainable agriculture principles that have proven useful in managing production risks created by weather variability and extremes include an emphasis on soil health, diversified production systems, ecological design and diversified, high-value marketing. Healthy soils buffer the farm or ranch from the increased variability and extremes in precipitation that currently challenge farmers and ranchers throughout the country. Diversified production systems build soil health and spread climate risks through the growing season, reducing potential losses from any single weather event. Ecological design reduces climate risk by creating production systems that are well adapted to the local landscape and climate. Ecological design also enhances ecosystem services that buffer production from weather-related disturbances and reduce costs. Diversified, high-value marketing spreads climate risks across multiple markets, improves profitability and produces social capital, all of which enhance capacity to respond to challenging climate conditions and to recover from climate-related damages.

weather event, a resilient farm or ranch has more capacity to avoid or reduce physical and financial damage than comparable farms and ranches using conventional management practices, and it can recover from damage more quickly. A resilient farm or ranch can also change more easily to meet the future challenges and opportunities created by changing climate conditions. The characteristics of climate-resilient operations also serve to buffer many other risks that make farming and ranching a day-to-day challenge.

Cultivating Climate Resilience on Farms and Ranches outlines the new challenges that changing weather patterns pose in agriculture throughout the United States, and what you can do to make your farm more resilient. By understanding the climate risks to your production system and practices that can reduce those risks, you can identify some management steps that will improve the resilience of your farm or ranch to changing climate conditions while allowing you to achieve your other sustainability goals. "You just don't know what's around the next corner, so you have to prepare for the worst," Price said. "Hope for the best of course, but you know, hope is not a plan."

[1] *Managing Climate Risk: New Strategies for Novel Uncertainty.* 2012. Walthall, C. et. al. In *Climate Change and Agriculture in the United States: Effects and Adaptation.* p. 136. USDA Technical Bulletin 1935

Jennifer Colby uses holistic management, or whole-farm planning, and rotational grazing to manage sheep, poultry and pigs on her Vermont farm. These strategies allow her to set goals and adapt as conditions change. *– Photo by Jamie Storrow, SARE Outreach*

Farmers and Ranchers Adapt to Changing Weather

Recent research shows that U.S. producers have already made changes, or expect to make changes, to adapt to the more variable weather and extreme conditions they are witnessing. Examples include:

- Corn and soybean farmers in the Midwest and Northern Great Plains are adapting to longer dry periods and drought, higher disease and insect pressure, increased heat stress, and more frequent extreme rains by implementing new in-field conservation practices such as cover crops, purchasing more crop insurance or adjusting their insurance plans, and adding new technologies.
- Producers in Mississippi, Texas, North Carolina and Wisconsin growing corn, cotton, grain sorghum, rice and wheat say that if weather variability and extremes continue to intensify, the changes they would be most likely to make include diversifying crops, buying crop insurance, modifying lease arrangements or exiting farming altogether.
- Maine farmers representing seven major commodity groups—potatoes, dairy, blueberries, vegetables, apples, beef and nursery plants—have adapted to more erratic weather, new pests and more extreme weather events through crop diversification, adding drainage or irrigation systems and more protected growing space, and ecological production practices that build soil health.
- Organic and conventional grain producers in Montana have adapted to more frequent and extreme drought by diversifying crops, improving soil health and increasing profitability by reducing costs and selling into high-value direct markets.
- Crop and livestock producers in Kansas report that changing weather conditions have increased variability of crop yields, pasture regrowth, and crop and livestock maturation rates. To adapt, these producers are testing new crops and production practices, reducing tillage, investing in more efficient irrigation and purchasing more production insurance.

Sources for these examples are (in order):

Climate Change Beliefs, Risk Perceptions, and Adaptation Behavior Among Midwestern U.S. Crop Farmers. 2017. Mase, A., B. Gramig and L. Propkey. Climate Risk Management 15: 8–17.

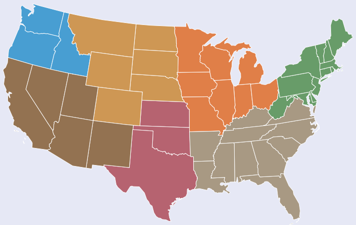
U.S. Agricultural Producer Perceptions of Climate Change. 2013. Rejesus, R. et al. Journal of Agricultural and Applied Economics 45: 701–18.

How to Communicate With Farmers About Climate Change: Farmers' Perceptions and Adaptations to Increasingly Variable Weather Patterns in Maine. 2014. Jemison, J. Jr., D. Hall, S. Welcomer and J. Haskell. Journal of Agriculture, Food Systems and Community Development 4(4): 57–70.

Raising Grain in Next Year Country: Dryland Farming, Drought, and Adaptation in the Golden Triangle, Montana. 2015. Stephens, Caroline M. University of Montana Theses, Dissertations, Professional Papers. Paper 4513.

Agricultural Producer Perceptions of Climate Change and Climate Education Needs for the Central Great Plains. 2014. Campbell Hibbs, A. et al. Publication of the University of Nebraska Public Policy Center. Paper 154.

TABLE 1. Observed and Expected Changes in Weather by U.S. Region



This table is adapted from the USDA Regional Climate Hubs' Regional Agricultural Vulnerability Assessments and the National Climate Assessment 2013 National Environmental Satellite, Data, and Information Service (NESDIS) reports. Alaska and Hawaii are not included, but can be found in the Northwest and Southwest Climate Hub reports, respectively. Expected changes are the A2 scenario at

SUMMARY OF OBSERVED AND EXPECTED CHANGES	ANNUAL TEMP	ANNUAL PRECIPITATION	GROWING SEASON
NORTHWEST: Higher temps, warmer winters, more frequent and intense heatwaves, more drought and more frequent wildfires are key climate change effects. Precipitation is more variable, especially in winter. Warming winters have increased rainfall, reduced snowpack, increased risk of flooding and soil saturation, advanced the timing of spring melt and reduced summer flow in river basins fed by snowmelt. The growing season is 11 days longer. These changes are expected to continue. Summer drought and winter flooding will become more frequent.	↑ • Greatest increase in the SE • Greatest summer increase in the interior • Greatest winter increase in SE Idaho	↑ • Greatest increase in eastern Wash. • Decrease in central Idaho and SW Ore. • Increase in most seasons; decrease in summer	**+25–35 DAYS** • Greatest increase west of the Cascades
SOUTHWEST: Average temps have increased in each season, most rapidly in winter. Heat waves have increased in frequency. Variability in precipitation has increased, with major droughts in the first two decades of the 21st century. The growing season is 14 days longer. Rising temperatures and shifting precipitation patterns, especially in the southern part of the region, are expected to alter crop productivity, crop-water requirements, crop-water availability, and costs of water access.	↑ • Less warming in coastal areas • Warming likely in all seasons, with greatest increase in summer	↓ • Largest decrease in the Sierra Nevadas and southern Ariz. and N.M. • Largest decrease in summer in parts of Calif., Ariz. and N.M.	**+10–38 DAYS** • Least change in Calif. and greatest change in the interior far west
SOUTHERN GREAT PLAINS: Average annual temp has increased. Hot periods are hotter and cold periods are warmer. The growing season is six days longer. Winters and springs are wetter; summers are drier; and snowfall amounts have decreased, particularly in the eastern part of the region. Drought and extreme precipitation events are more frequent. These trends are expected to continue. The number of days over 100 degrees and nights over 80 degrees will quadruple. Heavy rains, flooding, drought and severe storms will become more frequent and intense.	↑ • Greatest increase in the summer and fall, and least in spring	↑↓ • Increase in the north and decrease in the south • Little change in spring except for a decrease in Texas	**+15–30 DAYS** • Greatest increase in SE Texas
NORTHERN GREAT PLAINS: Temps have risen annually and in all seasons. Northern areas warmed at the fastest rate in the nation over the 20th century. The growing season is six days longer. Winters and springs are wetter and summers drier. Snowfall has decreased, particularly in the east. Drought and extreme precipitation events are more frequent. Warming is expected to continue on average and in each season. Changes in precipitation vary by location and season, but include earlier snowmelt and stream flow runoff, a shift to more rain than snow, and snowpack declines.	↑ • Greatest increase in winter and summer • Greatest summer increase in southwest Wyo. • Greatest winter increase in Neb. and N.D.	↑↓ • Decrease in the south and increasing northward to a maximum in the NE • Greatest increase in winter and fall; greatest decrease in summer	**+20–30 DAYS**
MIDWEST: Higher annual temps, warmer winters and springs, and more extreme precipitation events during the growing season are key climate change effects. Annual temps have increased, with warmer winters and springs, and cooler summers. The growing season is nine days longer. Precipitation has increased, especially in spring, summer and fall. Snowfall has decreased in the south and west but has increased in the north, in Indiana and along the Great Lakes shorelines. These temperature and precipitation trends are expected to continue annually and in most seasons.	↑ • Greatest winter increase in NW Minn. • Greatest summer increase in the south	↑ • Greatest increase in the far north; little or no change in the south • Increase in winter, spring and fall; no change to a decrease in summer	**+22–30 DAYS** • Greatest increase in northern Mich.
NORTHEAST: Temps have increased annually and in each season, and total precipitation has increased, especially in fall. Rainfall intensity has increased notably, particularly in the north. More intense heavy rainfalls, milder winters, earlier spring melt and sea-level rise have increased the risk of flooding. There are more hot days, fewer cold days and more intense rain. The growing season is nine days longer. These changes are expected to continue and will vary by location and season. The frequency and intensity of flooding will increase, especially in winter and spring.	↑ • Both annual and seasonal temps increase with latitude • Seasonal increase greatest in winter and summer; least in spring	↑ • Greatest increase in N.J. and Del. • Seasonal increase greatest in winter • Summer precipitation expected to decline	**+19–27 DAYS**
SOUTHEAST: Annual and seasonal temps have steadily increased since the 1970s, particularly in summer in coastal regions, while winter temps have generally cooled over the same areas. The length of the growing season is unchanged. Seasonal precipitation patterns are changing, with the greatest changes in fall (increase) and summer (decrease). Average annual snowfall has declined. Average temps and precipitation are expected to increase; however, the rate of change will vary with location and season.	↑ • Greatest change in the NW; least in the SE • Seasonal increase greatest in summer, especially in the NW	↑ • Greatest increase in winter • Summer precipitation increases or decreases depending on area	**+0–30 DAYS** • Least change in southern Fla. • Greatest change in the north and in southern La. and Ala.

mid-century (2041–2070 average). Definitions of terms: growing season–the period between the last occurrence of 32° in the spring and first occurrence of 32° in the fall; hot days–annual average of days with max temp exceeding 95°; hot spells–max number of consecutive days with max temps over 95°; cold days–average annual number of days with min temp below 10°; freeze days–days with a min temp below 32°; wet days–average annual number of days with precipitation over 1 inch; dry spells–max number of consecutive days with less than 0.1 inch of precipitation; heat and cold wave–a four-day period that is hotter and colder, respectively, than the threshold for a one-in-five-year recurrence for the region; extreme precipitation–the occurrence of one-day, one-in-five-year extreme precipitation for the region.

HOT DAYS	HOT SPELLS	COLD DAYS	FREEZE DAYS	WET DAYS	DRY SPELLS
+10 DAYS • Greatest increase in the SE	+6–10 DAYS • Greatest increase in southern Idaho	-10–30 DAYS • Greatest decrease in inland regions • Little or no decrease in coastal regions	-30–40 DAYS • Greatest change at high elevations	↑ • Greatest increase in eastern Wash. and Ore., and northern Idaho	+9–15 DAYS • Greatest increase in western Ore.
+5–20 DAYS • Least change at high elevations and greatest change in the south and east	+8–16 DAYS • Increase of 20 days or more in the south	-0–25 DAYS • No change in the south • Greatest change at higher elevations in the interior north	-25–35 DAYS • Greatest change at high elevations • Little change in coastal areas and southern Calif. and Ariz.	↑ • Increase, except for a decrease in eastern Colo., Ariz. and the Sierra Nevadas	+15–25 DAYS • Greatest increase in dry areas of Nevada, Arizona and California
+20–30 DAYS • Greatest increase in SW Texas	+8–24 DAYS • Greatest increase in northern Texas and Okla.	-0–10 DAYS • Greatest decrease in the north	-0–20 DAYS • Greatest decrease in the west	NO CHANGE	↑ ↓ • Decrease by up to three days in Neb. • Increase by 6–15 days in most of Okla. and Texas
+0–20 DAYS • Greatest increase in SW Neb.	+0–12 DAYS • Greatest increase in the south	-10–25 DAYS • Greatest decrease in southern Mont. and western Wyo.	-15–21 DAYS • Greatest decrease expected in the northwest	NO CHANGE	↑ ↓ • Decrease in the north by as much as six days • Increase in the west by up to 15 days
+5–30 DAYS • Change increases moving south	+5–20 DAYS • Change increases moving south	-10–25 DAYS • Greatest change in the NW • Least change in the south	-18–23 DAYS • Greatest decrease in the east	↑ • Greatest increase in the states bordering Canada	+0–8 DAYS • Greatest increase in the north • A slight increase in the south
+3–21 DAYS • Greatest change in parts of W.Va. and Md. • Least change in the region's northernmost areas	+1–7 DAYS • Greatest change in W.Va. • Least change in N.Y. and New England	-6–24 DAYS • Greatest change in the north • Least change in the south	-18–26 DAYS • Smaller changes likely along parts of the Atlantic coast	↑ • Greatest increase in NW N.Y. and northern Maine	NO CHANGE
+4–35 DAYS • Least change in the Appalachians • Greatest change in south central Fla.	+4–20 DAYS • Least change in the Appalachians • Greatest change in the west	↓	-0–25 DAYS • No change in southern Fla. • Change increases moving north	↑ • Greatest increase in the Appalachians	-0–25 DAYS • Greatest change along the Gulf Coast • No change elsewhere

Part One

Understanding Climate Risk

Longer and more severe periods of drought have a widespread impact on agriculture, particularly on dryland acreage in such states as Colorado (top, in 2012). Meanwhile, recent periods of unusually intense rainfall have caused extreme flooding, as pictured in Mississippi in 2011 (bottom).

– Photos by Lance Cheung, USDA

CLIMATE RISK IS THE ADDITIONAL RISK TO PRODUCTION and the farm business created by the ongoing rise in weather variability and extremes. It is expected to become an increasingly important factor in agricultural production in the years ahead. Over the next few decades, the entire United States will warm by about 2 to 4 degrees Fahrenheit. This rate of warming is substantially greater than the rate of change experienced over the course of the 20th century. There will likely be more winter and spring precipitation in the northern parts of the United States and less precipitation in the Southwest, while summer and fall precipitation is likely to remain about the same or decrease in most regions. Both the frequency and intensity of heavy rainfall events are projected to increase.

Although it can be very difficult to determine the exact influence of weather variability on year-to-year productivity and finances, you can better understand the climate risk to your operation by assessing its vulnerability to changing weather patterns and extreme events.

Vulnerability is generally characterized by three things: the weather-related challenges you are likely to face (known in climate risk management as *exposure*); how those challenges can threaten your operation (*sensitivity*); and how well your operation can both minimize weather-related damage and take advantage of new opportunities created by changing conditions (*adaptive capacity*). Adaptive capacity is what we typically mean when we refer to resilience. (See Figure 1.)

Examples of adaptive capacity include the ability to relocate annual crop production out of a flood plain or change to a more flood-tolerant enterprise; shift to new tree-fruit cultivars or a new fruit species with lower chill requirements; diversify crop rotations and use pest and disease forecasting; or plant a longer-season crop or an additional crop succession.

Anticipating weather-related threats and identifying the steps you can take to protect your production system by considering exposure, sensitivity and adaptive capacity will help you reduce climate risk.

For example, although no one can stop a drought from happening (exposure), you can take steps to reduce the damage it will cause your farm or ranch (sensitivity), for example by shifting to forage varieties or livestock breeds that are more tolerant of dry conditions. Likewise, in anticipation of more frequent and intense droughts, you

could increase the resilience (adaptive capacity) of your operation the way Gary Price did, by improving soil health so that your soils can store more water between rainfalls.

Understanding Exposure

Is climate change likely to affect weather patterns in your region? What does this mean for your farm or ranch? Understanding how the climate is already affecting the weather in your region, or is likely to affect it, gives you some of the information you need to estimate the climate risk to your operation. Exposure describes the type and intensity of climate effects already occurring in a specific location or that are likely to occur in the future. These effects might include more weather variability, more persistent or extreme drought, higher nighttime temperatures or more rainfalls that lead to flooding, for example. As the frequency and intensity of local climate exposures increase, so does the vulnerability of your farm or ranch.

Paul Muller co-owns and operates Full Belly Farm, a 400-acre diversified organic farm growing fruits, vegetables, grains and livestock in the Capay Valley of Northern California. Although water conservation has always been a management priority, climate challenges such as heavy rainfalls that happen more frequently, longer dry periods and continuing drought have prompted him to emphasize sustainable water management. "The last couple of years we have had the driest Januarys and Februarys on record," Muller said in 2013. "That's the time of year we normally get the moisture that goes deep in the ground, the moisture that serves as the reservoir for our crops that come in the spring. They get their roots down deep and draw on that water. The last couple of years, it just hasn't been there."

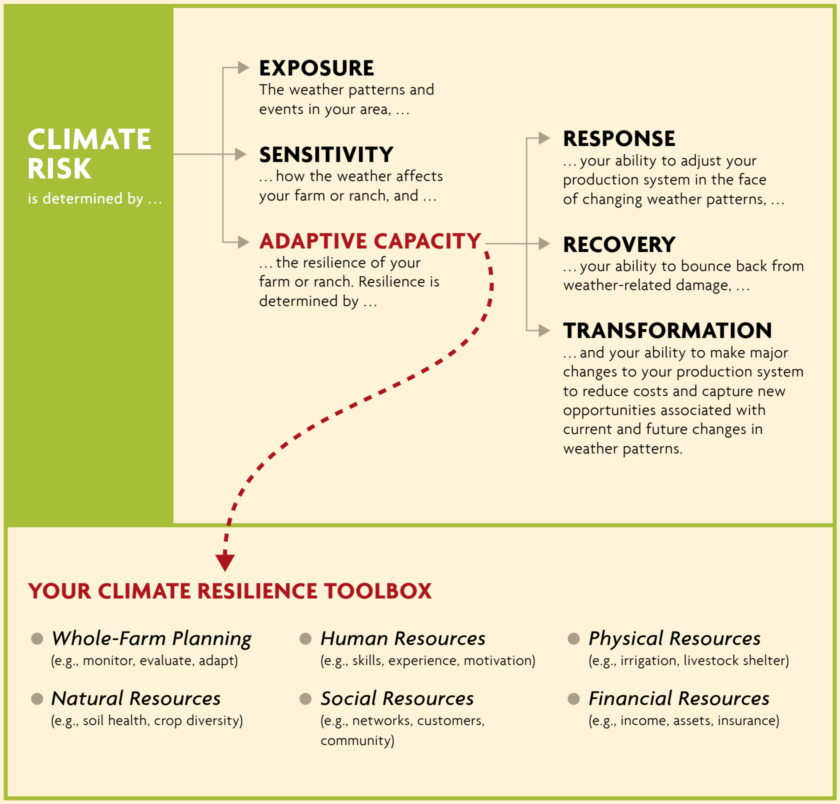
Dan Shepherd cannot say he has noticed any clear trends in changing weather patterns in the 40 years he has been farming, but the last decade or so has included several unusually extreme weather-related events on his farm. He manages 4,000 acres of commodity crops, including 300 acres of pecans on fertile floodplain soils along the east fork of the Chariton River near Clifton, Mo. Recent weather challenges include total crop loss from a late frost for the first time in 2007; flooding from the first levee breach in July 2008, which happened again in 2013; and three dry summers in a row starting in 2011.

The U.S. climate record shows that over the last century, average temperatures have increased, nights and winters have grown warmer, the growing season has lengthened, precipitation patterns have grown more variable, and there has been an increased frequency and intensity of extreme weather events. These changes are not consistent across the country but have occurred in regional patterns. Since these weather-related challenges are expected to continue to increase in frequency and intensity through this century, they are a new source of additional uncertainty to agricultural risk management. (See Table 1.)

Understanding Sensitivity

Sensitivity refers to how the individual elements of the production system—crops, livestock, pests and diseases, land, infrastructure and people—respond to climate-related events. Because the sensitivity of your operation is a result of the interaction between the elements of your operation and the local climate challenges you may face, it is very place-based and farm specific. Sensitivity varies depending on the kind of crops or livestock you manage. For example, neighboring farms, one managing tree fruit and the other managing diversified vegetables, will not have the same sensitivity to warmer winters and more variable spring weather. On the fruit farm, a late spring frost during bloom has the potential to cause total crop loss, but on the vegetable farm it could actually increase crop yield and quality.

FIGURE 1. A Strategic Way to Think About Climate Risk and Resilience



Crop Sensitivities to Climate

As weather patterns increasingly vary, the sensitivity of crops becomes more pronounced, forcing growers to adjust in various ways, often by changing the crops they grow or by altering the timing of their rotations. Already, in some parts of the country, heat waves and hot nighttime temperatures are disrupting fruit set in vegetable crops and reducing yields in grain crops. Warming winters and more variable spring weather are also disrupting crop development, especially in crops like winter grains and perennial fruits and nuts that require a dormancy period before flowering.

During the last 15 years, as summer temperatures increased and drought became more common, Alex Hitt started noticing a decline in production of some of his crops, particularly tomatoes. He grows four acres of vegetables and flowers in Graham, N.C.

"In 2012, high temperatures were near 100 degrees for more than two weeks in early June," Hitt said. "We've had some heat-related pollination problems in tomatoes, squash, beans and cucumbers. Temperatures were just too hot for fruit set." High fall temperatures have also caused problems, sometimes scalding the tomatoes on the vine. Drought has interfered with normal plant development, causing time to maturity to become more irregular.

In Missouri, the weather extremes of 2013 hit Shepherd's pecan trees particularly hard. Spring flooding and drought through the summer stressed the trees and lowered yields. "Being underwater for a week or two really set them back," he said. "And June 23 was the last rain we had until somewhere up in the middle of October, so that hurt the fill on the pecans." Climate has a large influence on crop growth, yield and quality through seasonal patterns of temperature and precipitation. Plants are most sensitive to extremes of temperature and moisture during the reproductive phase in which flowering, pollination, fertilization and fruiting occur. The effects of temperature extremes are amplified by soil moisture extremes, which often occur together, such as a heat wave accompanied by drought.

Every plant species has a set of optimum temperatures that best support its growth and development. These temperature optimums change through the phases of the plant's life cycle. For example, lettuce seeds have an optimum soil temperature range of 43 degrees to 70 degrees, and they will not germinate at a soil temperature below 38 degrees. Lettuce plants can grow in air temperatures ranging from 45 degrees to 77 degrees, with an optimum between 64 degrees and 77 degrees. If the weather gets too hot, lettuce will grow poorly and harvest quality can greatly decline. Table 2 shows the temperature regimes of some important annual food crops.

If the temperature moves out of a plant's optimum range, growth and development processes are slowed as the plant diverts resources to adjust to these adverse conditions. Plants can maintain some growth in temperatures outside of their optimum range, as long as the change is gradual, but that growth will be suboptimal at best. Signs that a plant's growth is slowing due to temperature extremes include leaf rolling and wilting (due to heat), and reddish-purple leaf coloring and water-soaked leaves (due to cold).

For most crops, growth and development is more rapid as temperatures increase, but only until the upper limit of the optimum range. High temperatures reduce the quality and yield of annual crops and tree fruits as they ripen in the summer and fall, and complicate post-harvest handling such as cooling and packing. High temperatures and direct sunlight can sunburn developing fruits and vegetables, sometimes even scalding or cooking them while still on the plant.

In addition to temperature requirements, crops do best when the soil

TABLE 2. Temperature Regimes of Some Annual Food Crops Grown in the United States

Includes temperature ranges and optimum temperatures (degrees Fahrenheit) for germination, growth and reproduction of selected annual food crops. Notice that optimum ranges for flowering and fruiting (reproductive) are cooler than the range for vegetative growth, and that flowering and fruiting fail completely at around 95 degrees for most crops.

CROP	GERMINATION SOIL TEMP MINIMUM	VEGETATIVE GROWTH MINIMUM	VEGETATIVE OPTIMUM	REPRODUCTIVE OPTIMUM	REPRODUCTIVE FAILURE
Corn	50°	46°	77–91°	64–72°	95°
Rice	60°	46°	91°	73–78°	95°
Wheat	40°	32°	68–86°	59°	93°
Soybeans	50°	45°	77–98°	72–75°	102°
Potatoes	40°	45°	64–77°	N/A	N/A
Onions	37°	45°	68–77°	N/A	N/A
Tomatoes	55°	53°	68–77°	59–68°	95°

N/A: The crop is not grown for its reproductive structure.

supplies enough water throughout the growing season to maintain healthy development despite changing environmental conditions. This need for adequate soil moisture is even more critical at high temperatures, just as people need to drink more water when they are outside on a hot day. Although plants have evolved many effective responses to maintain growth and development under conditions of variable soil water, many have critical growth phases during which too much or too little water can cause irreversible damage that greatly reduces crop quality and yield.

Limited soil moisture causes some plants to shift from vegetative to reproductive growth and complete their life cycle early, at much reduced seed yield and quality. Moisture shortages at later growth stages can likewise reduce both crop quality and yield. A continuous supply of water is particularly important for fruit and vegetable crops because optimum water availability increases fruit size and weight while preventing defects such as tough, cracked or misshapen fruit. Other common plant responses to drought include wilting, rolling, shedding and reducing the number and size of new leaves.

On the other hand, waterlogging during germination and the seedling stage often results in total crop failure. Many crops are very sensitive to waterlogged soil and can literally drown if the condition persists for more than 24 hours. However, there is considerable variation in crop tolerance to water-saturated soils. For example, depending on growth stage, soybeans can survive waterlogged conditions for only 48 to 72 hours, while corn can survive for two weeks and winter wheat nearly a month.

Like specialty crops and row crops, the productivity of grasslands and forage crops are also regulated by the interaction of seasonal patterns of temperature and moisture with local soil conditions. Given sufficient soil moisture, either from rain or irrigation, higher temperatures tend to increase grassland and forage production as long as temperatures remain within a productive range; however, if water is limited, high temperatures can reduce yields.

The same is not true for nutritional quality, which is determined by several interacting factors such as temperature, precipitation, soil nitrogen availability and carbon dioxide (CO_2) levels in the atmosphere. Both increases and decreases in the nutritional quality of grasslands and forages have been observed in response to rising temperatures and CO_2 levels. If soil nitrogen levels remain the same or decrease as temperatures and CO_2 levels increase, these changes can stimulate plant growth and reduce protein content. Increasing CO_2 levels combined with more variable water availability can reduce the protein content of grain crops. Rising temperatures and CO_2 levels can also change the mix of species present in the grassland, which can increase or decrease forage quality. Given this degree of complexity, regularly monitoring pasture and forage yield and quality will become an increasingly important management tool.

Flooded corn in a Mississippi field.
– Photo by Lance Cheung, USDA

Livestock Sensitivities to Climate

Like plants, animals have temperature and water requirements that support healthy growth and development, and their sensitivity to climate exposures varies over their life cycle (e.g., young animals are most vulnerable to temperature extremes). Temperature and water requirements vary by species and breed, and are influenced by physical traits (e.g., coat color or thickness). Unlike plants, animals can respond to environmental stresses, at least in some cases, by moving to a more comfortable location. For example, unconfined animals often seek shade as temperatures rise or move to sheltered areas during high winds or heavy rains. Note that the ability of animals to move to a cooler area is not possible in confined feeding operations, such as is typical of poultry, hogs and often cattle being fattened with grain for eventual slaughter.

Because well-managed livestock typically receive adequate water and food, the key climate sensitivities in livestock systems are extreme temperature and humidity. Livestock can acclimate to gradually changing temperatures, but long periods of temperature extremes or extreme or rapid fluctuations in temperature will reduce productivity and can sometimes result in death. Combinations of wet conditions, cold temperatures and wind during the spring birthing period, a particularly sensitive time in the life of an animal, can present significant challenges to producers managing livestock outdoors.

This empty water hole on a California ranch was caused by drought in 2014. *– Photo by Cynthia Mendoza, USDA*

FARMER SOLUTIONS

Throughout this bulletin, passages with the Farmer Solutions icon show how farmers and ranchers around the country are putting resilience strategies into practice.

FS At Sap Bush Hollow Farm near Cobleskill, N.Y., where Jim Hayes produces lamb, beef, pork and poultry on 160 acres of pasture and woodlands, heavy rains have grown more common over the past 15 years and have increased surface water flows and ground saturation. "We were getting quite a bit of flow down the valley and quite a bit of groundwater coming up and saturating the areas where we keep the livestock during the winter," Hayes said. So, he built a new drainage system to redirect surface runoff and a new barn with a raised concrete floor to provide dry shelter for livestock.

Livestock producer Ron Rosmann suspects that increased weather variability, especially extreme temperature swings in winter, are creating stress in his cattle. He produces feed and food grains, beef, pork and poultry on 700 acres in the rolling hills of western Iowa near Harlan. "It used to be that the cattle could tank up on feed because you could count on the cold spell hanging around a couple weeks," Rosmann said. "Now we've got 50-, 60-degree swings in a matter of days, plus you throw the wind in. That's the biggest change I've seen in my lifetime. We've always had those variations but not continually. You'd have longer periods in between. These extreme swings are hard."

Changing Patterns for Weeds, Insects and Disease

Changes in temperature and precipitation patterns, coupled with increased levels of atmospheric CO_2, also change the incidence, population levels and competitive ability of weeds, insect pests and diseases. Changes that favor pests and diseases can increase production risks and often require modifications to management practices to maintain crop and livestock yields and quality.

Complicating matters is that an increased reliance on pesticides combined with an increasingly favorable environment for pest reproduction can speed up the development of pesticide resistance. In addition, losses to productivity can be compounded when a climate effect favors a pest species while also placing temperature- or moisture-related stress on a crop or livestock species.

Weeds. With unpredictable temperatures and varying water availability, weed management will become more difficult, especially in seasons that become warmer and wetter, because weed growth will speed up while the period in which soil conditions permit cultivation will become narrower and more variable. Herbicides may also become less reliable because increasing atmospheric CO_2 levels have varying effects on herbicide efficacy. For example, a two-year greenhouse study conducted by the USDA Agricultural Research Service in Beltsville, Md., found that at elevated CO_2 levels, the efficacy of glyphosate, the most commonly used herbicide in the United States, was reduced for lambsquarters, Canada thistle and quackgrass. Its efficacy in the study was unchanged for pigweed.

Longer growing seasons have made weed management on Rosmann's Iowa farm more difficult. This is especially true for giant ragweed. A long-term challenge in the low-lying areas of the farm, giant ragweed began moving uphill during the last five years. "We historically were not even thinking about planting corn until May 1, but now the giant ragweed are already getting big by then," Rosmann said. "They are a tough weed to take out with cultivation." Rosmann thinks the combination of wetter weather in May and June, earlier spring warm-up, and the longer growing season are promoting the spread of the weed.

With warming temperatures, current weed distributions will likely shift north, changing the mix of weed species on the farm or ranch as some common weeds leave the system and new weeds enter. Fluctuating water availability will have highly variable effects on weed success because drought tolerance varies widely among both weed and crop species. As a general rule, farmers and ranchers can look to comparable production systems to the south or in regions where current climate conditions are similar to projected conditions in their region for insight about troublesome weed challenges ahead. Monitoring weed populations and the efficacy of weed-management efforts will also become important under changing weather conditions.

Insects. Many of the observations about climatic effects on weeds hold true for insect pests. With warming temperatures and longer growing seasons, pest populations increase because pest species can produce more generations in each growing season, which can lead to more damage to crops and livestock. These conditions also change the mix and relative numbers of existing populations and create opportunities for the introduction of novel species. For many pests, it also appears that rising temperatures to date have reduced stress from cold temperatures and have thus increased winter survival without adding stress from maximum temperatures. This has led to a northward expansion of range without a southern retreat.

Management of insect pests will almost certainly become more challenging and costly as pest populations increase, generation times decrease and ranges expand northward. For example, sweet corn has traditionally been treated for corn earworm from 15 to 32 times per season in Florida, four to eight times in Delaware and zero to five times in New York. As growing conditions similar to Florida's extend northward due to changing weather patterns, an increase in the abundance of earworm is likely to extend with it, increasing pest-management costs. In addition, more frequent pest reproduction and increased exposure to pesticides through a longer growing season can lead to the development of resistance to pesticides more quickly.

There is some evidence from the tropics that a changing climate may reduce the efficacy of existing cultural and biological pest-management strategies as well. For example, changing seasonal weather patterns have disrupted the synchrony between pest and control agent in some tropical crops like oil palm. In theory, if predator and prey respond to different cues—one to changing temperatures, the other to changing day length, for example—then the chance of a mismatch is high. If the predator is a specialist, then there is a greater chance that a timing mismatch will reduce predator populations. Mismatches like these will likely have the greatest effect on crop damage early in the growing season when it is most likely that a mismatch between predator and prey will happen. Agricultural scientists expect that these sorts of mismatches in agricultural crops will grow more common in the future.

Because of these uncertainties and a lack of research-based information, regular on-farm monitoring of insect populations will become increasingly important as a way to keep track of changing pest populations and the performance of insect-pollinated crops. As with weed management, to get a glimpse of future insect pest challenges, producers can look to comparable production systems under climate conditions that are similar to those projected for their region.

Diseases. Like weed and insect management, disease management is likely to become more difficult and costly. Changes in seasonal weather patterns, more extreme weather events and increasing atmospheric CO_2 levels are likely to cause changes in the timing, spread and ability of disease organisms to cause infection. This will complicate cultural and biological management, and if producers rely increasingly on pesticides as a result, it may cause resistance to emerge more rapidly. The introduction of new crops and livestock that can better deal with climate risk may also have the unintended consequence of increasing the risk of introducing new diseases, and may create new opportunities for existing diseases as well.

Like other growers in the humid East, Elizabeth Henderson, who has grown organic vegetables at Peacework Organic CSA for more than 25 years near Newark, N.Y., has seen a startling increase in crop disease with the changes in weather over the last decade. "In my first 15 years of farming, we never lost an entire crop to a disease," Henderson said. "You would have some disease on some of the crop, or some pest, but in the past 10 to 15 years, we've had things like powdery mildew blow in and entirely wipe out all the cucumbers. Or late blight totally wipe out the tomatoes and potato crop."

The corn earworm's range is expected to expand northward as weather patterns continue to change.
– Courtesy North Carolina Cooperative Extension

Management of insect pests will almost certainly become more challenging and costly as pest populations increase, generation times decrease and ranges expand northward.

Hotter summers, more frequent heavy rainfall, more frequent drought and novel diseases have required some adjustments to the Henderson farm's management practices.

The same is true of Ken Dawson. At his 16-acre diversified organic vegetable farm near Durham, N.C., earlier arrival of downy mildew, a devastating disease of cucurbits, has required Dawson to adjust his plantings of crops like cantaloupes and winter squash. Downy mildew survives the winter in Florida and moves up the East Coast as summer temperatures increase.

"It used to be that downy mildew would appear in eastern North Carolina in early August and then move westward," said Dawson. "We could safely grow susceptible crops up until sometime in August and then those diseases would come. In the last three or four years, downy mildew has started appearing in June. In response to that, we shifted our plantings of susceptible crops earlier by at least a month, because if we plant it later, it all dies before it matures."

In addition to the impact on crop health, regional warming and variability in seasonal rainfall patterns may also change the spatial and temporal distribution of livestock diseases sensitive to temperature and moisture, such as anthrax, blackleg and hemorrhagic septicemia, as well as increased incidence of ketosis, mastitis and lameness in dairy cattle. This may be compounded further by the fact that weather-related stress can compromise livestock resistance to disease.

Jim Hayes has noticed that wetter conditions and warmer temperatures, particularly in winter, have increased parasite pressures in his sheep flock. "We've been here a long time and the winters are not anywhere near as severe as they used to be," he said. "About eight years ago or so, we started really having problems with heavy parasite loads."

Hayes found that conventional deworming practices were becoming less effective, so he started using the FAMACHA system to manage the use of dewormers and to increase the flock's natural resistance to parasites. The FAMACHA system involves regular monitoring of the level of infestation of Haemonchus, a major parasite of sheep, with a simple eyelid test. FAMACHA is widely used among small ruminant producers in the United States and has been the focus of extensive SARE-funded research and education projects by agriculture professionals and producers.

To reduce parasite pressures, Hayes also shifted to a novel type of rotational grazing, known as mob grazing. This involves managing pastures in more mature growth phases with high-intensity grazing over very short time periods. "Now we're letting the grass grow longer and we may only take 30 percent of the available forage from the top down," Hayes explained. "We have a higher residual level of thatch, and the sheep aren't grazing so close to the ground, so we're having fewer parasite problems." He has noticed some other benefits of mob grazing as well, including better weight gains, increased forage production, better production during dry periods, faster recovery after grazing and improved soil health.

"We have been in and out of a drought since 1998, more in a drought than out, so water out here is everything."

– *Jacquie Monroe, third-generation Colorado farmer*

Many producers are turning to efficient systems like subsurface drip irrigation as they adapt to having less available water.

– *Courtesy USDA*

Soil and Water Resources

Soil health and the quantity and quality of water resources are extremely sensitive to climatic changes, particularly given more frequent and intense weather extremes. Wind and water erosion degrade soil health. As more variable precipitation narrows the window for time-sensitive fieldwork such as planting, cultivating and harvesting, the risk of soil degradation increases because producers may be forced to carry out operations when the soil is too wet or too dry.

Russ Zenner has been farming in the Palouse region of Idaho, near the town of Genesee, for more than 40 years. He manages 2,800 dryland acres in a three-year rotation of winter wheat, spring grains and spring broadleaf crops. More rainfall in the spring and drier conditions in late summer and fall have complicated crop management for him. During the record-breaking wet spring of 2011, Zenner believes he created some compaction problems by planting on soils that were extremely wet, and he has been struggling to restore those soils ever since. He thinks that the damage done in 2011 has increased the incidence of soil-borne diseases on his farm.

Along with the potential to degrade soil health, longer growing seasons and warmer winters also increase the potential for soil nutrient losses by extending active nutrient cycling by soil microorganisms into the winter months. This longer window of soil nutrient availability increases the risk of nutrients leaching to groundwater, particularly during periods of heavy rainfall. More frequent and extreme rains will also increase the loading of nutrients, sediments and pesticides into surface waterways, especially if producers use more fertilizer and pesticide inputs in response to increased weather-related uncertainties.

In addition to soil and water quality concerns, water availability is widely recognized as the most critical near-term resource sensitivity for agriculture. More frequent and intense extremes of temperature and precipitation, along with increased variability, are already creating significant disruptions in water supplies throughout the country. This challenge is expected to grow more pronounced in coming years. Rising temperatures and shifting precipitation patterns have begun to alter the patterns of agricultural demand for water, as well as its availability and cost, throughout the United States.

Jacquie Monroe, the third generation to own and manage Monroe Family Farms, has been struggling with water shortages for almost 20 years. The 200-acre farm, which produces vegetables and all the pasture, hay and feed grains needed to raise beef, pork, lamb and eggs, is located northeast of Denver, the fastest-growing large city in the United States. “We have been in and out of a drought since 1998, more in a drought than out, so water out here is everything,” she said. “We have to irrigate in order to get a crop, so water is a huge problem.”

Monroe’s 22-year-old son is weighing the pros and cons of joining his parents in the farm business. He would like to become the fourth generation on the farm, but competition for water in the region makes it difficult to imagine a lifetime in farming. “We are very concerned about our water rights and whether or not we’re going to be able to get our water in the future,” Monroe said. “The cities are buying the water off the farms and taking it back to the city. They say that 700,000 acres are supposed to be dried up in the next 10 or 15 years. It means that water will never go back to those farms. Once it’s gone, it’s gone forever.”

When it comes to water management, climate is not the only source of pressure on producers. In many parts of the country, they face competing societal demands for water as urban and residential populations grow and land-use patterns change. Some of the largest demand increases are projected in regions where groundwater is the main source of water, such as the Great Plains and parts of the Southwest and Southeast. Competition for water among agricultural, industrial and public uses has reduced water supplies to agriculture in the West and Southwest, and a similar situation is on the horizon in the relatively water-abundant Southeast.

Other Climate Sensitivities: Management, Operating and Maintenance Costs

Along with the challenges of managing new pests and diseases, changes in crop and livestock growth and development, shorter windows for timely fieldwork, more variable yields, and more competition for declining water resources, climate change will also increase operating, maintenance and overhead costs in many production systems. This will be due to reduced product quality and yields, production failures, loss of markets, and increased input and insurance costs. If current conditions create a high-stress production environment for you, your employees, your crops, your livestock or your customers, the additional challenges presented by climate risk may represent a key sensitivity of your operation.

Steve Ela grows a diversity of fruit varieties on his Colorado farm and direct markets them, two strategies that improve the resilience of his operation and help him maintain profitability.
– Photo by Laura Lengnick

In 2011, Jim Hayes’s Sap Bush Hollow Farm was right in the path of back-to-back hurricanes Irene and Lee that caused catastrophic flooding in South Central New York. The storms were an eye-opening experience for everyone in the community, said Hayes, particularly with respect to how quickly the road system in the area was destroyed. “The damage that those storms caused was very frightening,” he recalled. “That really reset our thinking.”

As a result, Hayes is actively working to identify and address major farm sensitivities to more variable and extreme weather, including disruptions to transport, power, feed, water and forage reserves, and loss of markets. His farm’s increased vulnerability to heavy rainfall and extreme weather “has come to be a major issue,” Hayes said. “We realize that these things aren’t going to go away.”

Adaptive Capacity and Climate Resilience

Because your operation is located in a specific place, it is subject to a unique set of ecological, social and economic conditions, all of which influence your management decisions. For example, ecological conditions such as local topography, seasonal weather patterns, climate and the quality of natural resources on the farm or ranch—particularly soil and water—shape the choices you make about the kinds of crops and livestock to produce and how to produce them. Similarly, your management decisions are influenced by social and economic conditions both on and off your farm or ranch, such as family relationships, family business, personal goals, government regulation and support programs, access to financial and technical resources, marketing opportunities and community support for agricultural businesses. Within the limits created by these conditions, you can take action to strengthen what is known as the adaptive capacity or resilience of your production system.

Resilience is the ability of a farm or ranch to respond to weather-related events in ways that avoid or reduce potential damages, to recover swiftly when there is damage, and to take advantage of new opportunities created by changing weather patterns.

Managing Temperature and Moisture Extremes

The effects of temperature and moisture extremes, which are expected to increase in frequency and intensity over the next 30 years, can be very difficult to manage. Heavy rainfall can interfere with field operations and cause labor issues, degrade soil health, threaten crops and livestock, and damage farm infrastructure. Drought can be challenging even with irrigation if access to a sufficient supply of water is threatened by climate change. Extremes of temperature and precipitation are often accompanied by other weather extremes, such as high winds or hail, creating a greater challenge than either extreme alone. In general, farms with lower sensitivity to extremes of temperature and moisture will have:

- healthy soils with a high infiltration rate and water-holding capacity
- healthy crops and livestock, including species, cultivars and breeds that can tolerate local weather extremes
- access to physical resources—such as housing, season extension structures, irrigation systems, frost protection, drainage, windbreaks, shaded areas, riparian areas and wetlands—that can buffer temperature and moisture extremes, especially during the most sensitive stages of plant and animal development
- managers with experience managing dryland production systems and/or irrigation

A farm or ranch with high adaptive capacity will be more resilient to changing weather patterns. Resilience is the ability of a farm or ranch to respond to weather-related events in ways that avoid or reduce potential damages, to recover swiftly when there is damage, and to take advantage of new opportunities created by changing weather patterns. As resilience increases, climate risk to your operation falls. A more in-depth look at how resilience works on farms and ranches and how you can manage for resilience is provided in Parts Two and Three of this bulletin.

Steve Ela, a fourth-generation grower near Hotchkiss, Colo., manages 100 acres of organic apples, pears, peaches, cherries, plums and tomatoes. Although the lengthening season has improved growing conditions for some fruits, production risks have increased, particularly in the last decade. “We’re experiencing earlier springs and more variable temperatures in the spring,” Ela said. “It used to be one year in 10 we would expect a really bad year, maybe another two or three years we would have some frost. Now we have frost every year. The one-in-10 year with a 10 percent crop, that still holds, but now we’re having 50 percent crops many other years.”

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While unsure if the weather changes he has noticed in the last decade are normal variations or early signs of climate change, Ela has nonetheless made a number of adjustments to his production system to improve his resilience and remain profitable. For example, in the past, farmers in his region did not need wind machines for frost protection, and Ela had only a few to protect particularly sensitive trees. Now, wind machines cover his entire farm. He has also diversified into new crops and more frost-tolerant cultivars.

Ela also began direct marketing his products about 15 years ago to retain more control over pricing. In a region that has lost 75 percent of its fruit growers over the last 20 years, he thinks that direct marketing, which provides high returns and product flexibility, has contributed to his continued success. “With the direct marketing,” he said, “more control on price means we don’t have to hit a home run every year to still be viable.” Direct marketing, he added, also provides his operation additional risk management because it allows him to plant varieties that might not be suitable for wholesale markets but have characteristics that can be handled in direct markets. The uniform product requirements of commodity markets, Ela said, increase

Whole-Farm Planning with Holistic Management

Holistic management is a whole-farm planning strategy that uses an ecosystem-based framework for the management of agricultural businesses. Developed by Allan Savory for the ecological management of South African grazing lands, it has developed into a planning strategy for the sustainable management of farms, ranches and conservation lands worldwide.

Holistic managers look at the "whole" of their operation and seek to understand the relationships between finances, the land and the people who work it. They set personal and business goals that describe their desired quality of life, the kinds of production needed to support that quality of life, and the natural and social resources needed to sustain that production over time. Holistic managers monitor progress towards these goals with performance measures that help them to "learn as they go" and make management adjustments as needed to stay on course towards their goals. Holistic managers have the benefit of some unique practices, including the three-part holistic goal, planning for profit, testing questions that guide sustainable decision-making and regular monitoring of personal, business and natural resource health and well-being.

Although holistic management is more commonly used on ranches and conservation lands in the western United States, new holistic management tools for crop producers have recently become available. Learn more at https://holisticmanagement.org.

risks in fruit production because growers are not free to select varieties best adapted to their particular farm conditions.

Enhancing Climate Resilience with Whole-Farm Management

Managing a farm or ranch to enhance adaptive capacity, or resilience, is admittedly complex. It requires thinking through your production system in terms of component parts and how the relationships between the parts contribute to the climate resilience of the whole operation. It requires making strategic management decisions that take into account many factors, some relatively simple and stable, and many others that are complex or can change rapidly. When faced with such challenging conditions, adaptive management has proven to be a useful tool.

One form of adaptive management that farmers and ranchers can use is whole-farm planning. Producers who have adopted whole-farm planning feel more confident in their management decisions and report improved profitability, enhanced quality of life and increased natural resource quality on their farms and ranches.

A key strategy in whole-farm planning is to regularly monitor production system conditions in order to evaluate and modify management actions to meet sustainability and resilience goals.

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Mark Frasier, owner and manager of Frasier Farms in Woodrow, Colo., draws on many resources to manage the challenges of weather variability and extremes. He believes the use of adaptive management strategies has proven vital to his success. Focusing on the key word, "variability," Frasier said: "You've got to have adaptive management to respond, both in terms of knowing how to respond and also to anticipate what a change will bring."

When warming winters and a lengthening growing season promoted an increase in parasite populations on his farm, recall that Jim Hayes began monitoring parasite loads in his sheep using FAMACHA. This information helped him conclude that his switch to mob grazing resulted in fewer parasite problems.

Although whole-farm planning can be an effective farm management tool, it has not been widely used. Many producers say the record-keeping required for effective monitoring is a barrier to adopting the management strategy; however, in recent years, new record-keeping tools that use smartphones and other digital technologies have made record-keeping easier, and whole-farm planning is a key feature of many beginning-farmer training programs. Adaptive management strategies like whole-farm planning are likely to become more important as climate risk adds increasing uncertainties and complexities to the challenges of managing agricultural businesses.

Julia Davis Stafford records data from a rain gauge on her family's New Mexico ranch. Stafford uses holistic strategies to manage rangelands and adapt to periods of low rainfall and drought.

– Photo by Laura Lengnick

See the Resources section for a list of tools and publications that can help you bring whole-farm planning to your farm or ranch.

Part Two

Understanding Climate Resilience

AS WEATHER-RELATED DISRUPTIONS BECOME MORE frequent and intense, climate resilience has become a new goal of businesses, organizations and communities around the world. Many farmers and ranchers are thinking about it too. But what does resilience really mean? How can it become a management goal on farms and ranches, and can progress toward it be measured?

Resilience is usually thought of as the ability to "bounce back" from a damaging disturbance or shock, but if you dig a little deeper into the science, you learn there is a lot more to it. Research shows that resilient farming systems rely on three different kinds of adaptive capacity to sustain performance in the face of change: response, recovery and transformation. Each type of adaptive capacity contributes to resilience in a different way, and resilient systems tend to exhibit all three capacities.

Response capacity describes how your operation copes with climate-related challenges as they happen—both those that are expected and those that are not—in order to avoid or reduce potential damages and to capture new opportunities. *Recovery capacity* involves having the reserves needed to swiftly and efficiently return to full function when weather-related events have damaged your operation in some way. *Transformation capacity* means having the ability to make fundamental changes to your operation that enhance its response and recovery capacity in the face of changing conditions now and into the future.

Thinking about resilience in this way—as a set of complementary capacities—helps you keep in mind the full range of options for managing climate risks to your operation. It also provides a useful way to assess your current risk management strategies and adjust them if needed in order to strengthen the overall resilience of your business.

Mark Frasier uses planned grazing practices to improve the health of the soil and grasslands on his Colorado ranch, and to enhance biodiversity.
– Photo by Laura Lengnick

Cultivating Response Capacity

The owners of Full Belly Farm, a 400-acre diversified organic farm in Northern California, have taken a number of adaptive actions to improve water conservation and thus the farm's capacity to respond to prolonged drought and erratic rainfall. These actions involve minor changes to the existing system including a switch to more drought-tolerant cover crops, the addition of cover crop mulches to conserve soil moisture and upgrading to more water-efficient drip and micro sprinkler irrigation systems. All of these actions serve to reduce the risk of specific threats—drought and erratic rainfall—to farm production, but do little to reduce the risk of other weather-related challenges such as more flooding rains, warmer winters and higher pest pressures.

Along with using targeted practices to manage specific risks, as was done at Full Belly Farm, response capacity also entails using practices that provide more comprehensive risk management benefits. In other words, response capacity enhances the overall resilience of operations to both expected and unexpected disturbances and shocks.

For example, many farmers and ranchers who operate highly diversified systems appreciate the flexibility that diversity gives them when it comes time to make management decisions based on actual or projected weather conditions. Grain and cattle producers like Gabe Brown in Bismarck, N.D., and Gail Fuller in Emporia, Kan., use dynamic crop rotations and cover crop cocktails in their dryland production systems. Both producers plant crops throughout the growing season, which gives them the ability to fine-tune their crop rotation plan to current weather conditions.

"That's the beauty of the diverse system of ours," Brown said. "At times, we want to plant the cover crop, and then if the weather conditions change, maybe it's dry, we'll change the mix of that species a bit for more crop types that can handle drier conditions, or vice versa. It just makes management so much easier."

Fuller, who produces cash crops and livestock on a 2,000-acre dryland farm, appreciates that cover crop cocktails allow him to meet multiple goals. "The first thing we do is look at the resource concern we have in a particular field before we design the mix for it," Fuller said. "Are you going to graze it? What time of the year are you planting it? What will the weather be like? When you guess wrong, there's still going to be something there that will grow. The more diversity we put in that mix, the more it protects us."

Dick Cates in Spring Green, Wisc., and Texas rancher Gary Price have both used managed grazing to produce quality beef and to restore native ecosystems on their land. Cates designed a managed grazing system to revitalize a native oak savannah on his farm and to restore a trout stream that runs through his pastures. Price has restored nearly

Cover Crop Cocktails

Cover crops are planted to provide many important benefits, such as supplying crop nutrients; suppressing weeds, insects or diseases; building soil health; protecting soil nutrients from loss; providing forages; and improving farm income. Sustainable farmers are increasingly turning to extremely diverse cover crop mixtures, or "cocktails," made up of eight or more cover crop species in an effort to restore soil health and achieve a wider range of benefits.

The specific mix of species varies with farming system, planting season and objectives, but the overall aim is to address specific resource needs while maximizing the capacity of the cover crop as a whole to flourish no matter the weather or soil conditions. High species diversity is the key to success, so cocktails typically include a mix of warm- and cool-season grasses, broadleaf species and legumes.

Colorado potato grower Brendon Rockey appreciates the soil health, fertility, pest management and additional income produced by cover crop cocktails. He has fine-tuned a diverse mix of plant species that he adds to his farming system in various ways: planted as a green manure rotation, in insectary strips and intercropped with his cash crop of potatoes.

Cover crop cocktails have allowed Brendon Rockey to reduce his water use by about 14 inches, and they have greatly improved both soil health and his bottom line.

Cover crop cocktails have allowed Rockey to reduce his water use by about 14 inches, and they have greatly improved both soil health and his bottom line. He now uses a two-year rotation of potatoes and a mixed-species cover crop because adding green manure is more profitable than growing a cash crop every year. "Bringing in a diverse cover crop improved our soil health so much that it had a huge impact on the productivity of our potato crop," he said.

The green manure mix has a variety of cool- and warm-season broadleaf and grass species, including buckwheat, sudangrass, purple top turnips, daikon radishes, oats, lentils, winter peas, pearl millet, Ethiopian cabbages and safflower. Parasitic nematode control is aided by sudangrass, while lentils and peas are nitrogen fixers. Radishes, turnips and oats are nitrogen scavengers, provide deep tillage and suppress weeds. Custom grazing this cocktail brings in some additional income as well as other unique benefits associated with the integration of livestock into his crop production system.

Colorado potato grower Brendon Rockey rotates fields to highly diverse cover crop mixtures to enhance the soil and his management of water (top). He also plants flowering strips in the field to reduce pest pressure (bottom).
– Photos by Laura Lengnick

To reduce pest pressure in his potato crop, Rockey plants a mix of flowering species in strips. The mix is designed to create the diverse architecture and long flowering times needed to support high populations of beneficial insects throughout the growing season. It includes oats, radishes, phacelia, several species of mustard, hairy vetch, lentils, sunflowers, a mix of clovers, buckwheat, fava beans, cosmos, cornflowers, marigolds, calendulas, four o'clocks, coreopsis, forget-me-nots, California poppies, baby's breath, balsam impatiens and sweet alyssum.

Rockey also uses another mix of cover crop species—field peas, chickling vetch, desi chickpeas, buckwheat and fava beans—that he intercrops with his potatoes. He began developing this companion cocktail after he saw a yield boost in a test plot of potatoes that included a companion crop of field peas.

For an extensive collection of cover crop resources, visit www.sare.org/cover-crops. Many resources exist to help you select the right cover crop species, including SARE's book *Managing Cover Crops Profitably*, the USDA Agricultural Research Service's *Cover Crop Chart* and the Midwest Cover Crops Council's selection tool. See the Resources section for more information.

Michigan apple grower Jim Koan (left) explains his business strategies to former USDA Farm Service Agency Administrator Val Dolcini (right). Koan's cider operation provides consistent cash flow in years when weather disrupts apple production.
– Photo by Savannah Halleaux, USDA

2,000 acres of native tallgrass prairie on his ranch using managed grazing, brush clearing and control, the reseeding of degraded croplands to native grasses and the restoration of wetlands. The restored ecosystems serve to buffer these operations from many climate-related weather effects, including flooding rains and drought, hot and cold temperature extremes, high winds and changes in seasonal weather patterns.

Innovative practices associated with diversification—such as cover crops, dynamic crop rotation, the integration of livestock into crop production, and pasture cropping—enhance both the response capacity and general resilience of the production system in a number of ways. Systems that use these practices spread production risks through the season by including crops that differ in their sensitivity to specific weather-related disturbances. Diversification and ecosystem restoration can also reduce production costs because the biodiversity in the system can reduce or eliminate the need for inputs such as fertilizers, pesticides and irrigation.

Crop and livestock diversification goes hand-in-hand with product and marketing diversification, which adds another dimension to response capacity and resilience. Spreading marketing risk among different markets can buffer an operation against shocks and, when high-value products or markets are included in the mix, can increase profitability. Because high-value direct and direct-wholesale markets often demand uncommon and value-added products, they offer a financial incentive for diversifying crop production and selecting unique crop cultivars that are well-suited to regional growing conditions.

Cultivating Recovery Capacity

Holding some critical resources in reserve is key to the recovery capacity of your operation. These reserves can be natural (feed and forage, soil health, biodiversity), human (management experience, ease with loss and change), social (community support, knowledge, skills, public assistance), financial (insurance and disaster payments, savings, access to capital) or physical (backup and alternative energy sources, storage, shelf-stable products). Resilient farms and ranches accumulate reserves across the full range of resources under management.

FS Jim Koan appreciates the way that recent weather challenges have forced him to think outside the box, anticipate what could go wrong and plan for the worst. The Flushing, Mich., apple grower began on-farm production of hard cider—JK Scrumpy's—in part to enhance the recovery capacity of his operation. By processing a portion of his apples into hard cider in years when yields are high, he has a non-perishable product he can sell in years when weather disrupts production. This helps him maintain his cash flow. "In 2012, we had only had 10 percent of our apple crop. I had half a million dollars invested in those apples," Koan said. "That was not as big an issue for me as it would have been if we hadn't had JK Scrumpy's. I can walk away comfortably saying that I actually made a profit in 2012."

FS Tom Trantham sees a recovery strategy in the highly diverse, pasture-based system that he employs on his Pelzer, S.C., dairy. Known as the 12 Aprils system, Trantham no-tills short-season annual forages into a perennial grass pasture. This dynamic system allows him to produce high-quality forage all year and to quickly recover from mistakes or unexpected weather. "There's always a challenge in farming," Trantham said, "but with my system, I am able to adjust. If one crop goes, another one's put right in. But when you've got a hundred acres of corn silage and you lose it, you don't have another shot until next year, so you're done for."

Investing in recovery reserves, like managing for the accumulation of natural, human and social resources, challenges traditional notions of economic efficiency because it redirects resources away from narrow production goals; however, recent research suggests that resilience and efficiency goals are complementary, and a balance of both is required to support the sustainability of the system.

Cultivating Transformation Capacity

Ultimately, the resilience of an agricultural business depends on taking a long view of the operation as a whole. What kinds of fundamental changes in production system practices, enterprises and markets could you make to enhance the overall resilience of your operation now and in preparation for the future?

Implementing transformation capacity involves making major adjustments that significantly alter the existing production system by changing the relationships among the people, crops, livestock and land in order to enhance the overall resilience of the operation. These kinds of transformative changes could involve shifting from monoculture to diversified crop production, integrating livestock into cropping systems, shifting from housed to pasture-based livestock production or switching from low-value commodity markets to diversified high-value direct and wholesale markets.

FS Trantham's pasture-based dairy system boasts many resilient characteristics, but it was not always that way. Like many American farmers feeling the pain of consolidation in the agricultural sector during the 1980s, Trantham was producing a lot of milk in a conventional operation but barely turning a profit. "I went through some really rough times in those days. We all did," he recalled. Although he had long been among the top milk producers in his state, rising feed and other input costs, and falling prices left him with few options when he was refused an operating loan in 1987. After some research into intensive grazing practices, he successfully guided the transition of his 90-cow dairy from a feed-based to the forage-based production system he continues to use today. He has dramatically lowered his costs while increasing herd health, milk quality and soil health.

Trantham's transformation from commodity dairyman to specialty milk retailer was complete when the Happy Cow Creamery opened in 2002. Whole milk, chocolate milk, buttermilk and eggnog are processed on farm and sold into regional direct-wholesale markets and at an on-farm store that also sells a diverse line of mostly locally sourced fresh and processed products including produce, fruits, butter, cheeses and meats.

FS Recall that Colorado fruit grower Steve Ela uses direct marketing strategies to remain in business in a region that has lost 75 percent of its fruit growers over the last 20 years. His family farm was on the same downward path as others in the region when he took over management in 1990. With declining profits taking a toll on family finances, he looked to direct marketing to turn the farm around. "We started making changes because of bad economics and now we direct market 100 percent of our fruit," Ela said. "We've completely changed our business model in 12 years. Fortunately it's worked; we're still here." Direct markets have also opened up new opportunities for him to diversify crops because his customers are willing, even eager, to try something new.

A good time to consider transformative changes to your operation such as those made by Trantham and Ela is when it looks like the costs—ecological, social or economic—of maintaining your current operation are growing unacceptably high, your operation begins to consistently fall short of meeting your goals, or it becomes clear that change is inevitable because of growing environmental, social or economic challenges.

North Dakota farmer Gabe Brown (left) discusses how he can improve soil health, a focal point of any climate risk management plan, with Jay Fuhrer of the USDA Natural Resources Conservation Service.
– Photo by Scott Bauer

Managing Resources for Climate Resilience

FARMERS AND RANCHERS ARE EXPERIENCED RISK managers accustomed to making tradeoffs between goals and available resources. Because risk management has traditionally focused on using financial and technological tools to reduce production risks, many farmers and ranchers have less experience with the risk management benefits of their other resources. Operating a farm or ranch with an eye toward reducing climate risk means taking a broader look at how all of your resources under management—natural, human, social, physical and financial—can contribute to the response, recovery and transformation capacities of climate resilience.

Resilient farmers and ranchers take advantage of the climate risk benefits provided by the full range of resources under management, including:

- *natural resources* such as healthy soils that buffer extremes of rainfall and temperature
- *human resources* such as a creative, effective and climate-literate management team that can identify challenges and opportunities, and act accordingly
- *social resources* such as a supportive community that supplies high-quality, reasonably priced goods, services and labor, and is home to profitable markets
- *physical resources* such as the infrastructure, equipment and technologies needed to support management goals
- *financial resources* such as a net income that sustains the farm business and supports a high quality of life for the people who live and work on the farm

In addition, combining complementary practices from these different resource types will allow you to enhance climate resilience far beyond each practice used by itself.

For example, healthy soils (natural) capture and store large amounts of water (natural), and so they reduce the need for irrigation (natural, social, financial and physical). They also sequester carbon from the atmosphere (natural); decrease production costs by reducing the need for such inputs as fertilizers, pesticides and water (financial); increase product quality (financial and social); and reduce the environmental impacts of production (social). As another example, diversified marketing can increase income (financial) and strengthen relationships with both communities and local and regional buyers (social).

The owners of Full Belly Farm in Guinda, Calif., employ a range of practices that strengthen the resilience of their business, from community engagement to a highly diversified production system, including multi-species grazing of cover crops in orchards.
– Photo by Laura Lengnick

Managing Natural Resources

A healthy natural resource base contributes to the climate resilience of your operation by buffering the effects of greater weather variability and extremes. Healthy soils, an adequate supply of clean water, robust crops and livestock that are well-adapted to your farming system, and diverse habitats that support beneficial organisms and other wildlife can reduce the impact of expected and unexpected weather-related events that increase costs and reduce yields and product quality.

Diversified production systems are climate-resilient when they are designed and managed to promote two ecological functions: functional and response diversity. *Functional diversity* means that your farm or ranch can support the ecosystem services that contribute to crop and livestock production. These ecosystem services can include the regulation of soil health, water quality and quantity, nutrient cycling, decomposition of wastes, the suppression of pests, crop pollination and climate protection (e.g., flood control, wind and temperature moderation).

Response diversity means that your operation can remain productive under a wide range of conditions that are potentially disruptive. There are usually a number of species capable of supporting a particular ecosystem service, and they will often perform best under different environmental conditions (hot, cold, wet, dry, high or low nutrient availability). In diversified production systems, when conditions prevent one species from providing a critical ecosystem service, others may be present and able to step in. For example, in a diverse cover crop mix or hedgerow planting, plant species with lower water needs can support pollinators and keep the ecosystem service of crop pollination going if drought conditions should occur, while other species in the planting are available to continue this function under normal or high-moisture conditions.

FS "We work to enhance those ecosystem services, as they're called, by continually planting more trees, more shrubs, more crops for pollinators, more windbreaks and more wildlife habitat," said Harlan, Iowa, farmer Ron Rosmann. "The diversity is what will continue to play a big role for us."

Many common sustainable agriculture practices promote healthy natural resources and ecological processes that are proven to buffer climate effects, including:

- diversified production systems that integrate cover crops, annual and perennial crops, livestock and wildlife
- planned diversity and integration of crops and livestock, including diversity in cultivar, species and age, across the landscape and through time
- diversified sources, including on-farm production, of critical production inputs such as energy, nutrients, water and seeds
- reduced tillage practices
- on-farm waste recycling, including the use of compost and manure
- intensive grazing strategies
- biointensive integrated pest management
- value-added enterprises
- diversified marketing strategies
- whole-farm adaptive management

Healthy Soil Cultivates Climate Resilience

High-quality soil is one of the most effective natural-resource-based climate risk management tools available. "If you can improve your soil resource and make those soils more resilient, you'll be able to weather those extremes in moisture and temperature much more easily," said North Dakota crop and livestock farmer Gabe Brown. "I can easily go through a two-year drought and it does not affect our operation to any great extent because the soil is so much more resilient."

Crop production practices that improve soil health include conservation tillage, the use of cover crops and the integration of livestock. Producers across the country are recognizing more and more the great value of protecting and enhancing the health of their soils through the use of such practices.

In February 2014, the first National Conference on Cover Crops and Soil Health, organized by SARE and the Howard G. Buffett Foundation, brought together 300 leaders in farming, academia, government, agribusiness and natural resource conservation to discuss how widespread use of cover crops could contribute to a more sustainable American agriculture. In conjunction with the conference, about 6,000 farmers took part in cover crops and soil health forums at USDA Natural Resources Conservation Service and Cooperative Extension offices across the country. Participants in these forums shared experiences and discussed strategies—such as policy incentives and barriers, research and education—to encourage the adoption of soil-improving practices. A follow-up conference was held in 2017.

Regional multi-day workshops on cover crops and soil health were subsequently held by Northeast SARE and Southern SARE in 2016.

Workshop recordings and other resources from these events are online at www.sare.org/cover-crop-conferences.

FS A longtime grower of certified seed potatoes and fresh market potatoes in Center, Colo., Brendon Rockey decided to drop barley from his two-year potato/barley rotation about 10 years ago and replace it with a mixed cover crop as a way to decrease water use. (See the section "Cover Crop Cocktails.") The change reduced annual water use in his operation by about 14 inches, and the switch had some other significant and unexpected benefits. "Bringing in a diverse cover crop improved our soil health so much that it had a huge impact on the productivity of our potato crop," Rockey said. The increase in soil health reduced input costs and increased potato quality so

An example of the rich organic matter and biological activity found in a healthy soil that is managed with no-till and cover crops.
– Photo by Ron Nichols, USDA

dramatically that Rockey found it was more profitable to grow one cash crop every two years than one cash crop every year.

Livestock producers can improve natural resources by using production practices that build soil health, diversified crop rotations that include annual forages, rotational grazing practices and perennial forage species that are better adapted to growing conditions, like Gary Price did when he restored native tallgrass prairies to his Texas ranch. You can also select for animals that are well adapted to your production system, available markets and local environmental conditions.

FS

On his North Dakota ranch, Gabe Brown has made changes to improve natural resources, particularly the soil, and to better fit his livestock production system to local environmental conditions. Back in the mid-90s, he suffered four years of back-to-back weather-related crop losses. Short on funds and unable to qualify for a production loan, Brown lacked the money to purchase fertilizers and pesticides, so he had to come up with a different strategy. "Since that time, I've focused on the soil resource and on improving the water cycle, energy cycle and nutrient cycle using holistic management practices," Brown said.

The average soil organic matter level at his ranch is now about 5 percent, and the soil infiltration rate has increased from 0.5 inches per hour to 8 inches per hour. According to Brown, the most effective climate-risk management tool that he has is the capacity of his ranch's healthy soils to buffer more variable rainfall and temperatures. Similar to Price, Brown uses management-intensive grazing and grazes his cattle on native prairie, improved pastures and annual cover crops. He also carefully selects cattle. "With the way we manage our livestock operations, there are very few weather-related events that will affect our animals," Brown said. "Due to our selection process the cattle are now more adapted to our environment. We raise cattle in a much more natural way now."

"With the way we manage our livestock operations, there are very few weather-related events that will affect our animals."

- Gabe Brown, North Dakota rancher

Practices that Brendon Rockey uses on his Colorado farm to build soil health include intercropping fava beans and other cover crop species with potatoes (left) and rotating fields to highly diverse cover crop cocktails (right).

– Photos by Laura Lengnick

Participants in a Farm Beginnings class organized by the Land Stewardship Project learn adaptive management and whole-farm planning techniques.

– Courtesy the Land Stewardship Project

Mitigating Climate Change? Agriculture as a Solution

There is mounting evidence that agriculture can play an important role in the effort to slow climate change. The Intergovernmental Panel on Climate Change estimates that agricultural soils have the potential to sequester from 4 percent to 12 percent of total annual global greenhouse gas emissions, and a recent study by the Rodale Institute estimated that up to 100 percent of annual global carbon dioxide emissions could be sequestered if all the world's agricultural lands were transitioned to regenerative organic practices.

A recent review of climate solutions in California agriculture found that sustainable and organic farming can significantly reduce the carbon dioxide (CO_2) emissions associated with crop and livestock production. For example: The substitution of nitrogen-fixing cover crops for purchased nitrogen fertilizers can reduce CO_2 emissions by up to 50 percent; pasture-based beef production uses about 50 percent less energy than feedlot beef production; and organic production systems use about 25 percent less energy than comparable conventional systems.

Many sustainable agriculture practices offer win-win solutions to climate challenges because they both mitigate climatic changes and enhance climate resilience. Practices such as conservation tillage and no-till combined with cover crops or compost, diversified crop rotations, rotational grazing and agroforestry are particularly effective at pulling CO_2 out of the atmosphere and storing it in the ground. Higher soil carbon content also enhances climate resilience on farms and ranches by enhancing soil health.

Farmers can also contribute to agricultural climate solutions in other ways: Choose suppliers who are committed to reducing emissions; participate in community-based mitigation programs; and adopt mitigation strategies on the farm or ranch when financially feasible. To learn more about these and other options for farmers and ranchers, see the National Sustainable Agriculture Information Service (ATTRA) publication, *Agriculture, Climate Change and Carbon Sequestration* and the SARE publication, *Clean Energy Farming: Cutting Costs, Improving Efficiencies and Harnessing Renewables.*

Managing Human Resources

Effective climate risk management will depend on human capacity, both on the farm or ranch, and in the local community, to learn, plan for and adapt to changing climate conditions. Taking action to enhance the resilience of your farm or ranch will likely make new and different demands on you, may increase production costs and will likely require a high level of financial and emotional flexibility.

Resilient farmers understand how important people are to the success of their business and they put effort into managing healthy educational, economic and social relationships both on the farm and in the community. Farm managers can cultivate high-quality human resources by promoting the skills, health, well-being and education of all the people who contribute to the success of the operation. This focus on a well-educated, creative, collaborative and experienced team recognizes the special role that people play in the design and management of resilient farms and ranches, and enhances an operation's capacity to manage change. At the same time, it enhances the quality of life for all who are engaged in the farming operation.

FS

California's Full Belly Farm has involved an active partnership since 1989 among four owners who live in three households on or close to the farm: Paul Muller, his wife Dru Rivers, Judith Redmond and Andrew Brait. Full Belly Farm was designed to be ecologically diverse to foster sustainability on all levels: from healthy soil to happy customers; a stable, fairly compensated workforce; year-round cash flow; and an engaging workplace that renews and inspires everyone working on the farm. The current business structure supports the integration of the individual skills of each partner and has required the partners to develop strong interpersonal and cooperative skills. "Partnerships are interesting, like a marriage," Muller said. "You're not king of the heap. You're constantly working together."

Networking with fellow farmers and ranchers is a powerful way to improve the success of your operation. Here, Lisa Kivirist (far left) of the Midwest Organic and Sustainable Education Service speaks with women farmers about cover crops as part of a SARE-funded workshop series. *– Photo by Jean Andreasen, North Central SARE*

The Full Belly Farm business model business model recognizes that farmworkers are essential to their success. "Part of the reason for diversity on this farm is to create stability for our workers," Muller said. Full-time employees receive health insurance and profit-sharing, and everyone on the farm—the farm partners, their family members and farmworkers—is encouraged to recommend improvements to existing operations and to experiment with new enterprises. According to Muller, "This is work that has some dignity if you give it some dignity."

FS Elizabeth Henderson, who runs Peacework Organic CSA in New York, believes that efforts to improve the adaptive capacity of farms are best focused on the human dimensions of agriculture. She now works with the Agricultural Justice Project, which provides certification and technical assistance on fair labor standards. "In these very, very challenging times, having one manager is not enough," Henderson said. "Everybody on a farm has to be constantly observing, trying to understand and working out how to be nimble together."

One way to develop an operation's human resources is to use whole-farm planning and holistic management practices. These strategies encourage full participation in production planning, the freedom to talk openly and honestly, the development of mutually agreed-upon goals, and regular monitoring and reporting of progress towards those goals.

Other helpful practices include the regular participation of farm management and employees in community-based education, research and development networks, including organizations that value place-based, traditional agricultural knowledge and traditional foodways.

Managing Social Resources

Support from the community, and your engagement with it, can enhance the climate resilience of your farm or ranch. High-quality social resources can include experienced mentors, networking groups and loyal customers, as well as the local businesses and public and civic organizations that produce the goods, services and markets important to the success of your business.

Common ways to cultivate resilience through community engagement include participation in and support for direct markets, marketing and retail cooperatives, labor unions, sustainability associations, food policy councils and advisory networks. These kinds of entities can strengthen community capacity to establish and maintain effective community organizations, develop successful adaptation plans and manage community-based recovery responses.

FS On their 130,000-acre, fourth-generation ranch in Cimarron, N.M., Julia Davis Stafford and family members have taken many steps to cope with more intense periods of drought and the shrinking snowpack in nearby mountains that provides much of their water. Along with efforts to improve soil health, conserve water and more carefully manage grazing, Stafford sees networking as a vital part of building the ranch's resilience. Through the Quivira Coalition, a local nonprofit that seeks to build the area's ecological, economic and social resilience, Stafford learns how to improve management practices and, just as importantly, she values the chance to connect with fellow ranchers and land managers over their shared experience.

"What is always tremendously encouraging to me is just the networking at these various agricultural gatherings, talking to people and going to listen to them speak," Stafford said. "Sometimes, particularly just after I get home from a Quivira Coalition conference, I feel we'll be able to sort through this and go on just fine. And sometimes I feel really anxious about how we will keep going on if these same patterns—the drops in moisture and increasing temperatures—continue."

On the farm, sustainable management practices that promote community well-being include hiring seasonal labor from the local community and supporting local businesses. Marketing and education strategies that increase knowledge about food production can cultivate mutual support and understanding between food producers and consumers. Examples include community-supported agriculture, farmers' markets, hosting school tours and summer camps, agritourism and farm internships.

Managing Physical Resources

More frequent and extreme events are already presenting hazards to critical infrastructure needed in agriculture, including roads, buildings used for production and processing, storage structures for feed, forage and farm equipment, and power and water resources. As a result, farmers and ranchers are making numerous adjustments in their physical resources: the materials, tools, equipment, technologies and infrastructure they use to manage their production system. They are purchasing, upgrading or adding equipment, irrigation, drainage, physical protection, heating and cooling systems, and emergency backup systems. Physical resources such as hoop houses, irrigation and drainage, pesticides and other pest control materials, and genetically engineered drought-resistant crops can provide targeted protection against specific climate exposures. They also help capture new opportunities associated with a changing climate.

Changes or improvements to physical resources are particularly common as a response to greater variability in precipitation patterns. For example, many producers who are increasingly challenged by more variable and shorter windows in which to complete fieldwork have responded by purchasing larger equipment or additional equipment (tractors and associated implements) to reduce the time needed to complete fieldwork and increase management flexibility. In addition, many farmers in the Midwest and Northeast are adding or upgrading infrastructure such as irrigation and drainage systems to cope with more frequent and intense drought and flooding rains.

FS In response to the 2011–2012 drought and increasing urban demand for water, the Monroes, who farm near Denver, switched their entire farm from furrow irrigation to much more efficient drip and pivot systems. "We want to make sure we can continue to grow vegetables, and the pivot and drip irrigation puts the exact amount of water throughout the whole entire system," Jacquie Monroe said.

FS On his 95-acre vegetable farm in Hustontown, Penn., Jim Crawford uses black plastic mulch as physical protection against more variable weather and extremes. This allows Crawford to catch favorable conditions for field preparation any time that they occur during the year. "What we have done now for six or eight years is to prepare beds and put plastic down on large acreage before we need it. That way the land is standing by and it's ready when we need it," he said.

With this soil protection, plus the use of hoop houses for additional environmental control in the spring and fall, Crawford has been able to significantly extend his harvests. "We have actually doubled the number of weeks that we harvest sweet corn and more than tripled the weeks of green beans," he said.

Livestock producers can consider upgrades to physical infrastructure that reduce animal stress during more variable weather. For example, they can add emergency heating and cooling systems or shade and cooling structures to existing buildings, build additional ponds or water-storage systems, and reinforce field shelters to withstand stronger winds and more damaging storms.

Changes or improvements to physical resources are particularly common as a response to greater variability in precipitation patterns.

Julia Davis Stafford and her family added this water tank to their New Mexico ranch as part of the infrastructure that supports their rotational grazing plan.
– Photo by Laura Lengnick

FS To reduce climate risks to Sap Bush Hollow Farm, Jim Hayes added drainage, built a new barn, reinforced portable poultry huts, increased feed storage, installed solar power and built ponds to capture and store water in every paddock on the farm.

Along with all the challenges posed by the changing climate, Hayes has also found new opportunity in the adaptations he has made. The new barn means he can shift lambing season from May to April, which ultimately represents a cut in costs. If April weather is cold

Adele Hayes stands in front of the solar panels she and her husband, Jim, installed at Sap Bush Hollow Farm, which help them cope with power disruptions caused by severe weather. In the background is the raised barn that ensures lambing can proceed regardless of weather conditions.
– Photo by Laura Lengnick

and wet, his sheep can lamb in the barn; if it is dry and warm, they can lamb in the open as they used to do in May. Earlier lambing gives the lambs more time to grow and mature during the best part of the grazing season. "We're looking at a longer grazing season, and we're stockpiling more for winter grazing," Hayes said. "The difference between winter grazing versus purchasing hay is almost a factor of 10, as far as cost. We hope to get a higher percentage of our animals finished before the grazing season ends, and it looks like we may be able to finish an additional batch of chickens each year as well."

Managing Financial Resources

Financial resources, which typically include family and farm income and assets, insurance, credit and cost-share programs, investments and savings, provide the necessary capital to invest in the other kinds of resources that you need to cultivate the response, recovery and transformation capacity of your operation.

A resilient farm or ranch has the financial capacity to offer a living wage and benefits to managers and farmworkers, and a reasonable return on invested capital. It also has the resources to provide education, family activities, retirement and other desired activities and services.

Business management practices that produce high-quality financial resources include sound financial planning, proactive marketing and effective risk management. Some key management practices that support financial resource management goals include:

- the adaptive management of profitable, diversified crop and livestock operations that are capable of accumulating high-quality natural, human, social and physical resources
- the creation of high-value products
- innovative marketing strategies that support sales into diversified, high-value markets and values-based regional food supply chains

Part Four

Getting Started: Exploring Your Risks and Assessing Your Options

RECALL THAT VULNERABILITY IS A KEY CONCEPT IN understanding your operation's climate risk. Thinking about climate risk in terms of sensitivity (the response of individual components of the production system to exposures) and adaptive capacity or resilience (the ability of the production system as a whole to buffer damages and capture new opportunities) can help you assess your operation's vulnerability. This in turn allows you to develop both short- and long-term strategies that are more likely to sustain your operation as weather patterns become more variable and extreme.

Creating a plan to manage climate risk and enhance the resilience of your operation is a step-wise process that involves answering four questions about the vulnerability of your operation to changing weather conditions:

1. What are the key weather-related challenges? The goal in answering this question is to identify current and near-term weather-related exposures specific to your operation. Table 1 summarizes current and expected changes in weather variability and extremes for seven U.S. regions.

2. What are the key production threats from changing weather patterns and extremes? The goal in answering this question is to prioritize climate-related threats specific to your operation. Experienced producers will already have a good understanding of the key sensitivities of their operation to typical weather patterns, but may have to do research to identify new and emerging sensitivities associated with increasing weather variability and extremes.

3. What are your options for addressing key weather-related threats? The goal in answering this question is to identify adaptive actions that address the key climate threats to your operation. You will want to develop a list of practices that enhance the response, recovery and transformation capacities of your operation. Be sure to include in this list practices that promote both specific and general resilience. A useful way to be sure you have considered all potential options is to think through, for each type of resource under management, the specific practices that enhance resilience and are a good fit for your operation.

4. What is the best mix of adaptation options? The goal in answering this question is to find the most appropriate mix of practices that reduce climate risks and capture new opportunities for your operation. Selecting among options will likely involve some cost/benefit tradeoffs typical of traditional risk management, but it can be difficult or impossible to estimate the costs and benefits of climate resilience practices because of the uncertainties associated with climate risk.

When evaluating potential adaptation options, remember to include a mix of complementary practices that work together to enhance the resilience of your operation both now and over the long term.

Be careful to avoid depending on just one or two practices that target specific risks, such as drought-resistant cultivars, irrigation, pesticides or insurance. Targeted risk management practices are often the best choice when addressing near-term, high-risk threats to the existing production system, but they can be costly, are likely to increase in cost and decrease in effectiveness over time, and may ultimately fail if the pace and intensity of climate change increase as expected.

Targeted risk management practices are most useful when they target high-value crops or livestock during sensitive life cycle stages (e.g., at birth, or during flowering or fruiting) and target high-value perennial crops near the end of a long production cycle, such as almonds or grapes. These practices can also be very useful during the early stages of a transition to a new, fundamentally different operation that positions the business to thrive in future climate conditions.

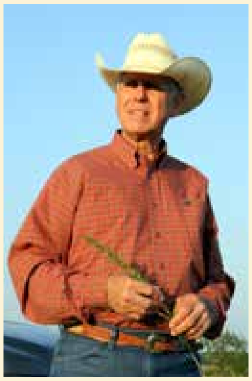
Charting Your Course in a Changing World

Climate risk is currently challenging many farmers and ranchers in the United States and beyond, and it is expected to increase in intensity through this century. Although we have much to learn about farming in a changing climate, sustainable agriculture, adaptive management and resilience thinking offer a useful set of principles, practices, tools and management strategies to reduce the risks and capture the opportunities created by the inevitable challenges ahead.

Gary Price is upbeat about the future of the 77 Ranch. He is confident that high-quality natural resources, easy access to technical support and his willingness to adapt will serve the ranch well in the years ahead. "We think we are on the right track," Price said. "Everything in ranching is a moving target; it's constantly changing, some things more than others. We must be very flexible in all that we do, and especially in our thinking, to adapt to changes. That's just the way it is."

"We must be very flexible in all that we do, and especially in our thinking, to adapt to changes. That's just the way it is."

– Gary Price, Texas rancher



– Photo by Karl Wolfshohl

Helpful Resources for Producers and Educators

GENERAL RESOURCES

Climate Change and Sustainable Agriculture: Curriculum and Handbook
A collection of resources to help producers and educators adapt to changing climate conditions. Michigan State University. www.sare.org/climate-change-and-sustainable-agriculture

Extension Disaster Education Network (EDEN)
A multi-state network of Extension professionals that offers research-based education resources on disaster preparedness and response. National EDEN site: https://eden.lsu.edu

Resilient Agriculture: Cultivating Food Systems for a Changing Climate
Explores agricultural climate risk and resilience through the adaptation stories of 25 award-winning sustainable farmers and ranchers producing vegetables, fruits, nuts, grains and livestock products across America.
www.newsociety.com/Books/R/Resilient-Agriculture

CLIMATE EXPOSURES — REGIONAL

Historical Climate Trends database
State-by-state data on temperature and precipitation trends beginning in 1895, with seasonal and annual data available.
http://charts.srcc.lsu.edu/trends/

State Climate Summaries— NOAA National Centers for Environmental Information
National Oceanic and Atmospheric Administration (NOAA) state-by-state reports on historic climate trends, projections for the 21st century, and sea-level conditions and coastal flooding.
https://statesummaries.ncics.org/

Vulnerability Assessments— USDA Regional Climate Hubs
These regional assessments report on regional climate exposures, sensitivities, adaptation and mitigation strategies for working lands. www.climatehubs.oce.usda.gov/actions-and-resources/vulnerability-assessment

CLIMATE RISK MANAGEMENT — REGIONAL

AgroClimate
Online decision tools to help farmers in the Southeast improve the climate resilience of their operation, from the University of Florida.
http://agroclimate.org

Cornell Climate Smart Farming Program
Online decision tools to help farmers in the Northeast improve the climate resilience of their operation.
http://climatesmartfarming.org/

Regional Approaches to Climate Change
This project was initiated to ensure sustainable cereal production in the inland Pacific Northwest and has produced a wide variety of resources to support agricultural adaptation to climate change in the region.
www.reacchpna.org/outreach

SustainableCorn.org: Crops, Climate, Culture and Change
Online tools and research to help Corn Belt growers adapt to changing climate conditions. https://sustainablecorn.org

USDA Regional Climate Hubs
Offers tools, strategies, management options and technical support to farmers, ranchers and forest land owners to help them adapt to climate change.
www.climatehubs.oce.usda.gov

FARM PLANNING AND RESOURCE MANAGEMENT

The Adaptation Workbook
An interactive, online adaptation planning tool for land managers. The tool guides users through a series of questions that explore the potential effects of climate change on their operation and how to develop a set of land-management and conservation actions that can help prepare for changing conditions. Northern Institute of Applied Climate Science.
https://adaptationworkbook.org/about

FarmData
An online recordkeeping system designed especially for organic vegetable producers that allows users to keep production records related to seeding, transplanting, harvest, cover crops, compost, fertilization, irrigation, pest scouting, spray activities, packing, distribution and customer invoicing. Dickinson College.
www.sare.org/farmdata

Introduction to Risk Management: Understanding Agricultural Risks
Designed to improve the risk management skills of agricultural producers by introducing some basic risk management concepts and effective management tools. L. Crane et al. 2013. USDA Risk Management Agency.
http://extensionrme.org/pubs/IntroductionToRiskManagement.pdf

Introduction to Whole Farm Planning: Combining Family, Profit and Environment
Briefly describes the four steps involved in this adaptive management approach to comprehensive planning, and recommends tools and resources. Minnesota Institute for Sustainable Agriculture. www.misa.umn.edu/publications/wholefarmplanning

My Observatory
A cloud-based GIS that you can use to collect data, including images, to monitor farm performance in all sorts of weather. www.my-observatory.com

Reading the Farm
An educational program that improves the ability of Extension professionals and others to give management advice to farmers and ranchers based on a whole-farm analysis of their operation. Northeast SARE and the University of Connecticut. www.sare.org/reading-the-farm

NATURAL RESOURCE MANAGEMENT

Building Soils for Better Crops
This one-of-a-kind, practical guide to ecological soil management provides step-by-step information on soil-improving practices as well as in-depth background information on soil properties. SARE. www.sare.org/bsbc

The Cover Crop Chart (v. 2.1)
This chart includes information on 58 cover crop species that may be planted individually or in cocktail mixtures. Information on growth cycle, relative water use, plant architecture, seeding depth, forage quality, pollination characteristics and nutrient cycling are included for most crop species. M. Liebig, USDA ARS.
www.ars.usda.gov/plains-area/mandan-nd/ngprl/docs/cover-crop-chart

Cover Crops Topic Room
This online collection of educational materials was developed out of decades of SARE-funded cover crop research. SARE. www.sare.org/cover-crops.

Diversifying Cropping Systems
This bulletin describes some of the many agronomic crop alternatives to use in rotations, with plentiful examples of on-farm successes. SARE. www.sare.org/diversify

Managing Cover Crops Profitably, 3rd Edition
This definitive book explores how and why cover crops work and provides all the information needed to incorporate cover crops into any farming operation. SARE.
www.sare.org/mccp.

The Midwest Cover Crops Council (MCCC)
The MCCC cover crop selector tools are online systems that assist farmers in choosing cover crops for field crop and vegetable rotations. http://mccc.msu.edu/selector-tool

USDA United States Department of Agriculture | National Institute of Food and Agriculture

SARE Sustainable Agriculture Research & Education

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