California Climate Hub
U.S. DEPARTMENT OF AGRICULTURE

ADAPTATION RESOURCES WORKBOOK FOR CALIFORNIA SPECIALTY CROPS

A Guide for Adaptation Planning

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Preferred citation:
Parker, L. E., Johnson, D., Pathak, T. B., Wolff, M., Jameson, V., and Ostoja, S. M. (2023). Adaptation Resources Workbook for California Specialty Crops. USDA California Climate Hub Technical Report *CACH-2023-1*. Davis, CA: U.S. Department of Agriculture, Climate Hubs. *55 p.*

Acknowledgments

Many individuals contributed their knowledge and expertise to the development of this workbook. The authors would especially like to thank the following agriculture professionals and members of the technical service provider community who served as expert reviewers, providing feedback and edits that improved the quality of this workbook.

Mark Battany, PhD, *UC Cooperative Extension*
Liz Colby, P.E., *USDA-NRCS*
Darcy Cook, *Mission Resource Conservation District*
Ben Faber, PhD, *UC Cooperative Extension*
Norm Groot, *Monterey County Farm Bureau*
Amy Lofting, *Meridian Farm*
Karen Lowell, PhD, CCA, *USDA-NRCS*
Wendy Rash, *USDA-NRCS*
Margaret Smither-Kopperl, *USDA-NRCS*

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A GUIDE FOR ADAPTATION PLANNING

Climate change and California agriculture

California agriculture is not immune to the risks of climate change[1,2] and specialty crops may be uniquely vulnerable to the expected climatic changes. California's climate has changed since record-keeping began in the late 1800s. Warmer temperatures[2] and earlier snowmelt[3] have been observed and in a warming world, we can expect changes in the frequency, duration, and intensity of droughts, floods, and heatwaves.[2,4,5,6,7,8] Warming winter temperatures will reduce the accumulation of winter chill that is needed for fruit and nut crops,[9] warmer springs may advance bloom in crops like almonds,[10] and warmer summers may mean earlier harvest for tomatoes.[11] Warmer temperatures can also influence the timing and intensity of pest pressure,[12] while extreme heat events place additional stress on crops and the water resources that farmers rely on to manage the heat.[7] All of these changes may have profound impacts on California's specialty crop production. In fact, some estimates suggest that climate change could reduce yields of specialty crops such as avocados, walnuts, and table grapes by as much as 40% by the end of the century.[13] In light of the downward pressure climate change may place on California agriculture, adaptation will be critical for maintaining the state's specialty crop production in the decades to come.

What is this workbook and who is it for?

This workbook provides resources and guidance for California's agricultural producers and technical service providers to help them identify actions for increasing resilience to a changing climate. The workbook was developed with specialty crop production in mind, but it contains useful climate adaptation information for many agricultural production systems.

What does "climate adaptation" mean?

Climate adaptation for agriculture encompasses actions that help farmers and the agroecosystems they manage cope with the effects of climate change. Actions that help to reduce the damages from climate stressors like heatwaves, droughts, or floods can be considered climate adaptive. Actions that help farms more readily recover from these events are also climate adaptive. Different types of adaptation frameworks exist depending on land managers' short- and long-term adaptation goals. For example, some natural resource land managers use the Resist-Accept-Direct (RAD) Decision Framework[14] to guide their management options for landscapes at risk of, or undergoing, ecological change. This framework helps managers decide whether to resist ecosystem changes and maintain historical conditions, or whether the most appropriate course of action is accepting the change as it occurs or actively directing the change toward preferred new conditions. The Resistance-Resilience-Transformation (RRT) framework[15] (Figure 1) provides another way to conceptualize potential adaptation actions. Similar to RAD, the RRT framework offers three different approaches to adaptation but RRT can provide a spectrum of paths towards adaptation, ranging from *active resistance* to *accelerated transformation*. Adaptation frameworks like RAD and RRT can help growers develop strategies for responding to climate change on their farms.

Climate adaptation actions tend to focus on withstanding current and/or projected future climate conditions, but many adaptation actions also have benefits for **climate mitigation**. These mitigation actions help to combat the effects of climate change by reducing greenhouse gas emissions or by sequestering (storing) carbon-based greenhouse gases from the atmosphere in plant matter and/or soils. In this workbook, you will mainly find climate adaptation actions, but we also include one section that is specifically devoted to climate mitigation, and we note when a given action provides both adaptation and mitigation benefits, sometimes referred to as co-benefits.

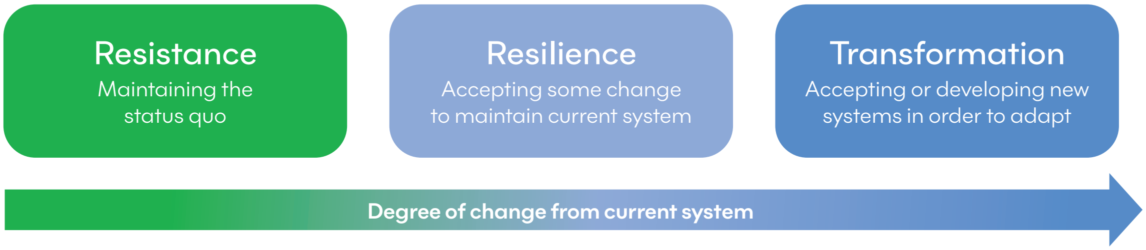


Figure 1. The Resistance-Resilience-Transformation typology provides one framework for understanding the range of climate adaptation actions available to producers. Different actions require or precipitate varying degrees of change from the status quo, but producers can choose actions from across the spectrum to meet their farm's unique needs and fit within their overall management plan.

How do I use this workbook?

This adaptation workbook draws on a 5-step process[16] (Figure 2) developed by the Northern Institute for Applied Climate Science (NIACS) for assessing the risks and vulnerabilities of land management goals to climate change, and it provides a path for developing a plan to address those challenges in California's specialty crop production systems. For each step, the workbook provides a brief description of that step's purpose and contextual content, followed by a corresponding worksheet that uses the concepts within the step and a series of guided questions to build a climate adaptation management plan. Collectively, these steps and worksheets guide users through the adaptation process, from defining one's goals and objectives through monitoring and evaluating the adaptive actions taken. We encourage users to read each step sequentially as the steps build on one another. The worksheets may be completed after each associated step or they may be completed together after reviewing all of the workbook steps. We suggest that you consider one goal or project at a time and complete each worksheet with that specific goal or project in mind.

Throughout the workbook, you will find references to resources that explore the relevant issues in greater detail, like Cooperative Extension guides, NRCS technical documents, and scientific literature. At the end of the workbook is a resources section with links to references that can further aid in adaptation planning. You can use this workbook and its 5-step framework to help guide you in developing a climate adaptation management plan that is specific for your farm's goals and needs.

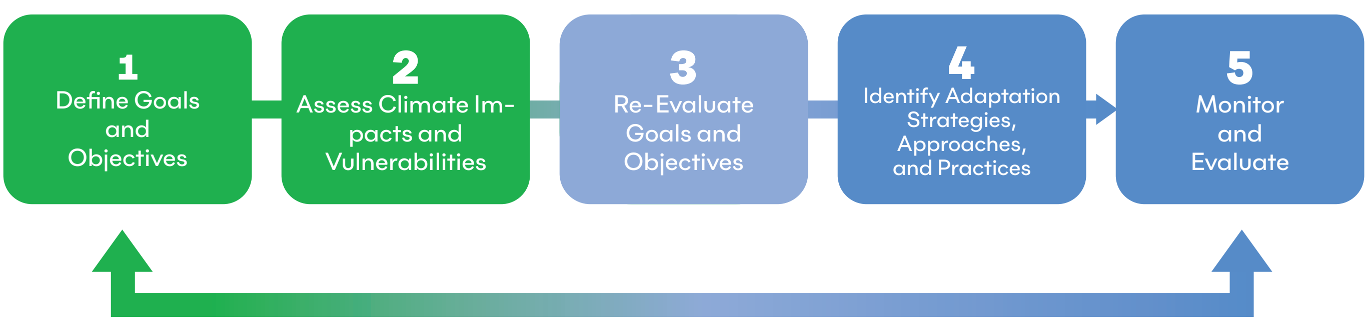


Figure 2. The five steps of this adaptation workbook offer a guide for improving the adaptive capacity of your farm by providing a structured approach for incorporating climate change considerations into farm management planning. More detail on the purpose of each step is provided in the associated workbook section. (Figure adapted from USDA reports [16,17])

STEP 1 DEFINE GOALS AND OBJECTIVES

The idea of adapting a farm to cope with the effects of climate change can seem complicated and feel overwhelming. But by breaking the process down into a set of sequential steps the process will feel less onerous. The purpose of Step 1 is to **define your management goals and objectives**, providing a foundational context for developing the plan that will help you achieve your specific interests. These management goals and objectives answer questions like "What is the long-term vision for your farm?" and "How will you achieve your vision?" These are likely things you already know and understand well, but perhaps they haven't been expressed or considered explicitly. Creating a management plan with clearly defined long-term goals supported by short-term objectives provides a solid foundation for effective climate adaptation.

Goals, Objectives, and Baselines

In developing a farm management plan, it may be useful to create goals and outline objectives for the different categories of farm management. Long-term **goals** frame a farm's mission and vision, whereas short-term **objectives** may be quantifiable and tangible targets that producers can work towards, providing a roadmap for executing and accomplishing pre-determined goals. Once the management goals and objectives have been identified, you may wish to establish a **baseline** or measure of the current conditions for each one to serve as a starting point against which changes can be compared and implemented, and adaptation actions can be monitored and evaluated (please see Step 5 for more on monitoring and evaluation). Box 1 below shows one example of how you can use a long-term goal and subsequent baseline measurements to better determine and refine your short-term objectives.

Box 1. Linking goals, objectives, and baselines can provide organization in the farm management plan.

Farm Management Category: Plant Health

Long-Term Management Goal: Decrease occurrence or impact of salinization

Baseline: Total Dissolved Solids (TDS) in soil based on soil salinity test

Short-Term Management Objectives*:

1. Reduce salt in soils via leaching
2. Improve drainage to facilitate salt leaching

*UCANR Publication 8550 Managing Salts by Leaching

Saline soils can negatively affect crop productivity. Adaptation actions such as leaching can help reduce the impacts of saline soils.

STEP 1 PUT IT INTO PRACTICE

Consider each of the guiding questions in the worksheets below. Remember, the collection of worksheets in this workbook provides a step-by-step pathway for developing your adaptation plan.

STEP 1 asks you to consider a specific management goal for your farm and identify the objectives for meeting that goal. Remember, **management goals** are broad, high-level outcomes, whereas **management objectives** are the approaches or actions that can help you meet your goals. Some examples of management goals and objectives can be found in Box 1 above.

Recall Box 1 on page 6. Now try filling out your own box below.

Project Name:	**Farm Location:**

Farm Management Category: *What would you like to focus on? Plant health, water storage, energy use, etc.?*

Management Goal: *What outcome(s) would you like to see for this category in the long-term?*

Baseline: *What measurable indicators can you use to assess your progress as you work towards your goal? It is usually very useful to take "baseline" measurements before starting new practices so the changes can be seen more clearly (see Step 5 worksheet).*

Management Objectives: *What are some actions you can take that will help you to meet your goal? Remember, your objectives should be quantifiable in the short-term and provide a roadmap towards meeting your long-term goal.*

STEP 2 ASSESS CLIMATE IMPACTS AND VULNERABILITIES

Global Changes, Local Impacts

Climate change is a global phenomenon, but the way it "looks" can vary widely from place to place. **Understanding the effects of climate variability and change** for a given location and production system is crucial for creating an adaptation plan that will provide operational resilience and improve adaptive capacity in the near- and long-term. Resources like CalAgroClimate, Cal-Adapt, Climate Toolbox, and the U.S. Climate Resilience Toolkit provide location-specific current and future climate information that can help producers assess the potential impact of climate change for their farm. For example, Cal-Adapt hosts various tools (Figure 3) that show how climate indicators like temperature, precipitation, and extreme heat have changed in the past and how they are projected to change in the future under climate change. By exploring these tools, growers can see what climate changes to expect and then use that information to assess the vulnerability of their farm or crop.

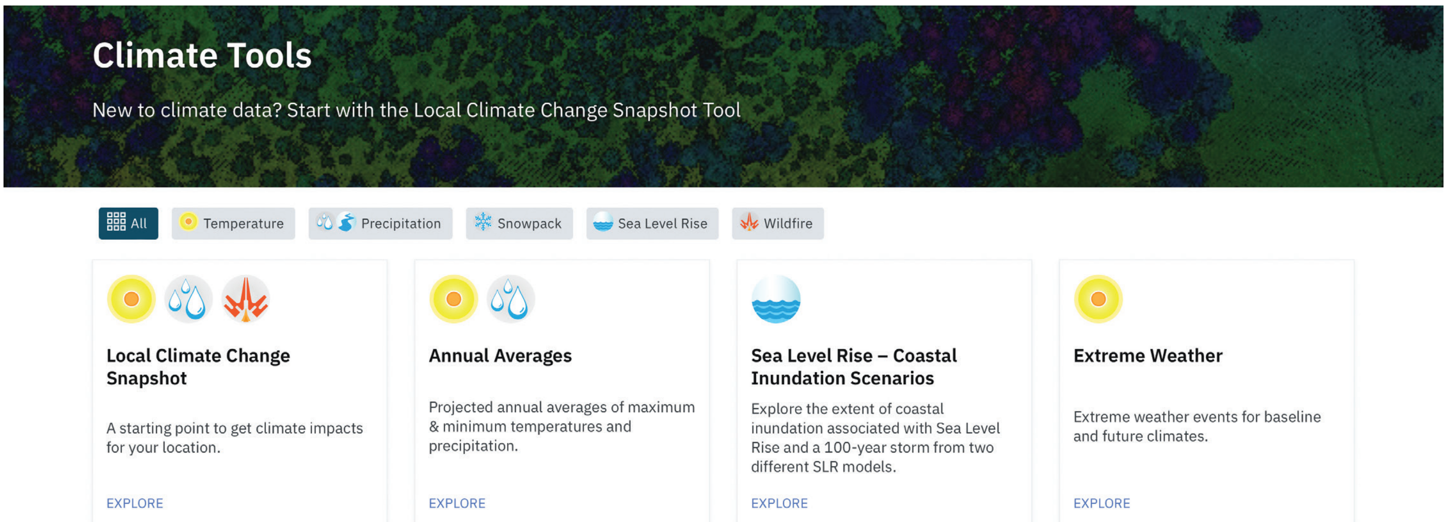


Figure 3. *Cal-Adapt has many useful tools for exploring California's climate at the local, county, or watershed scales. The website also hosts helpful how-to guides and informative documentation for first-time users and experts alike.*

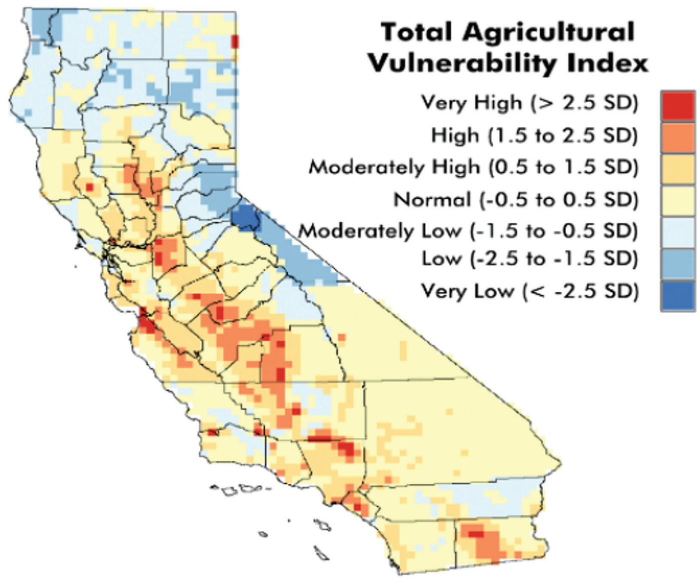
Determining Vulnerability

Determining how vulnerable a farm or crop system is to climate change is an important step in developing an adaptation plan. A farm or crop's **vulnerability** is defined by the degree to which it can cope with the adverse effects of climate change, including climate variability and extreme events.[18] In addition to a location's climate conditions and expected climate changes, factors like water security, crop tolerance to unfavorable conditions, and site characteristics like topography and soils – not to mention social and economic factors – all influence how susceptible a region or farm is to climate-caused damages. A farm or crop system's **adaptive capacity**, that is, its ability to adjust to changes, take advantage of opportunities, and cope with disturbance, can also impact vulnerability.[18]

Understanding the specific vulnerabilities of your farm or ranch will help you to pinpoint the parts of your operation that are most at risk due to climatic changes, and where you should focus your attention as you create your adaptation plan. Region- or cropping system-specific **vulnerability assessments** can provide additional context that may be helpful in assessing a farm's vulnerability to current and future climate conditions. The State of California's Climate Change Assessment website and the ResilientCA website provide multiple resources for assessing climate impacts and vulnerability. The California Energy Commission's report on its vulnerability index for California agriculture (shown on the next page in Figure 4) offers another resource for assessing farm-specific climate vulnerabilities. While these tools and resources provide good general information, determining an individual farm's vulnerability may also require working with experts such as RCD, NRCS, or cooperative extension staff, farm advisors, or other trusted technical assistance providers.

Figure 4. The vulnerability index for California agriculture accounts for many factors, including climate exposure, crop sensitivity, land characteristics, and socioeconomic vulnerabilities. Much of the state's specialty crop production area falls into the moderately high to very high vulnerability categories. That being said, this map does not take into account any climate smart management practices growers may have implemented to better prepare their land for climatic changes.

*This figure is available in the 2012 California Energy Commission Report **Vulnerability and Adaptation to Climate Change in California Agriculture**[19] and is reprinted here under Creative Commons License Attribution 4.0.*



STEP 2 PUT IT INTO PRACTICE

STEP 2 has you explore different dimensions of climate change and what they might mean for your farm. Climate change is globally dynamic, but the associated impacts and potential vulnerabilities are going to depend on your location and the crops you are farming, among other factors. To **assess climate impacts and vulnerabilities for your farm**, check out the resources mentioned above and consider the guiding questions in the box below.

Key Climate Concerns: What are the three most important climate factors that have the greatest potential to influence your farming operation? Consider things like growing season length, seasonality, duration and intensity of heatwaves, drought, extreme precipitation and flooding, chill accumulation, frost damage, wildfire and smoke, damage from insects or diseases, etc.

Climate Projections: How will climate change influence these key concerns? For example, will climate change increase or decrease the incidence of extreme precipitation and flooding, or the frequency of heatwaves at your location? Tip: Use tools such as Cal-Adapt to help you determine the climate projections in your area.

Potential Impacts: What would change in terms of your on-farm operation with these projected changes? Would a longer growing season provide opportunities for new crop rotations? What about pest pressure? Consider both the potential challenges and opportunities that could come from the anticipated climate projections for your location.

Vulnerability: How vulnerable is your farm to these projected climate changes? Consider whether your farm expects few, some, or many impacts, and the capacity your farm has to cope. Would you describe your farm as having Low, Moderate, or High vulnerability?
Low – Your farm is ready and able to cope with the potential climate change impacts.
Moderate – Your farm will experience some challenging climate change impacts, but it will be able to cope with others.
High – Your farm's ability to cope with the impacts of climate change is limited and climate change will disrupt many important aspects of your farm's operations.

STEP 3 RE-EVALUATE GOALS AND OBJECTIVES GIVEN PROJECTED IMPACTS AND VULNERABILITIES

Understanding how climate change can affect the successful implementation of management goals and objectives allows producers to re-evaluate farm management goals and objectives in light of projected impacts and potential vulnerabilities.

By evaluating management objectives with climate change in mind, producers can revise their management plan to be better suited for a future of environmental change. For example, the management goal outlined in Box 1 was to decrease the occurrence or impact of salinization, with an objective of reducing the salts in soils via leaching. However, if a vulnerability assessment shows that this objective is not feasible due to reduced water availability, it would be necessary to revise the objectives in order to achieve the reduced salinization goal (Box 2).

Box 2. When the original management goals and objectives are considered in light of climate impacts, a revised objective can help you meet your management goals despite climate challenges.

Original Management Goal: Decrease occurrence or impact of salinization

Original Management Objective: Reduce salts in soils via leaching

Climate Change Impact: Reduced water availability due to drought may make leaching infeasible

Revised Management Objectives*:

1. Reduce application of fertilizers and/or salt-containing amendments like manure
2. Plant crops that are more salt tolerant

*UCANR Publication 8550 Managing Salts by Leaching

How will climate change make my goals more challenging?

Do I need to change any of my goals or management objectives given my farm's climate vulnerability?

Are there any opportunities that climate might present for my operation?

Figure 5. When re-evaluating management goals and objectives given climate change implications, in can be helpful to consider your farm's unique vulnerabilities to climate change, along with potential opportunities the future may bring.

Identifying areas of potential difficulty in light of the effects of climate change can help you determine the inputs or resources needed for climate adaptation (Figure 5). Inputs are anything put into the farm system to improve it, such as capital investments, infrastructure, labor, or soil amendments. Inputs also support the actions taken to achieve goal-driven outcomes. In the example listed in Box 2, selecting the fertilizer based on baseline salinization concerns is the action, fertilizer type is the input, and the resulting salinization levels after using the new fertilizer is the outcome. Once you have revised your goals and objectives in light of climate change, the next step in this workbook introduces a menu of adaptation strategies, approaches, and practices that provide a means to select your climate-adaptive actions for farm management.

STEP 3 PUT IT INTO PRACTICE

In the **STEP 3** worksheet below you have an opportunity to recall the management goals and objectives you initially outlined in Step 1. In this step, consider how your Step 1 goals and objectives may be affected by climate change.

First, refer back to your worksheets for Steps 1 and 2. What are some of the challenges and opportunities that climate change presents for your farm management goals and objectives?

Management Goals and Objectives: What management goals and objectives did you outline in Step 1? **Use these to guide your answers to the following questions.**
Challenges: Consider your responses to your Step 2 worksheet. How will climate change make it more difficult to carry out your objectives and meet your goals?
Opportunities: Will climate change provide opportunities to further your goals and objectives?

After completing Steps 1 and 2, if you have determined that climate change will require a change in your management plan, use the boxes below to organize your re-evaluated goals and objectives with climate change vulnerabilities and challenges in mind.

Re-Evaluated Management Goal: What is your new or adjusted long-term management goal?
Re-Evaluated Management Objectives: What are your new or adjusted objectives? Do you need to reconsider your baseline for measuring progress?

STEP 4 IDENTIFY ADAPTATION STRATEGIES, APPROACHES, AND PRACTICES

Central to the adaptation process is identifying appropriate actions that can buffer a farm to the environmental shocks caused by climate change. In this step, an adaptation "menu" is presented. It offers science-based information for developing a farm management plan that incorporates climate adaptation. The menu consists of a collection of potential adaptation applications, organized by strategy, aimed at addressing the concerns related to climate change.

What is the Adaptation Menu?

In order to develop a successful adaptation plan, producers will need to identify a set of actions that can help them meet their climate-adjusted goals and objectives. The adaptation menu provides a starting point in selecting appropriate actions for adapting an operation to the current and future climate. The menu is organized by adaptation strategies, which are very high-level actions that may be applicable across landscapes and production systems. Within each strategy, approaches provide guidance on how a particular strategy might be implemented and more detailed information on the importance of the approach for agricultural adaptation. Each approach may be adopted by enacting one or more practices (Figure 6). The practices included in the menu do not represent an exhaustive list, but they are potential on-the-ground applications that accommodate the selected approach and strategy. The menu focuses on adaptation, but some approaches and practices can provide the secondary benefit of mitigating climate change by reducing greenhouse gas emissions or facilitating carbon sequestration. *Note that Strategy 7 is entirely focused on mitigation efforts.

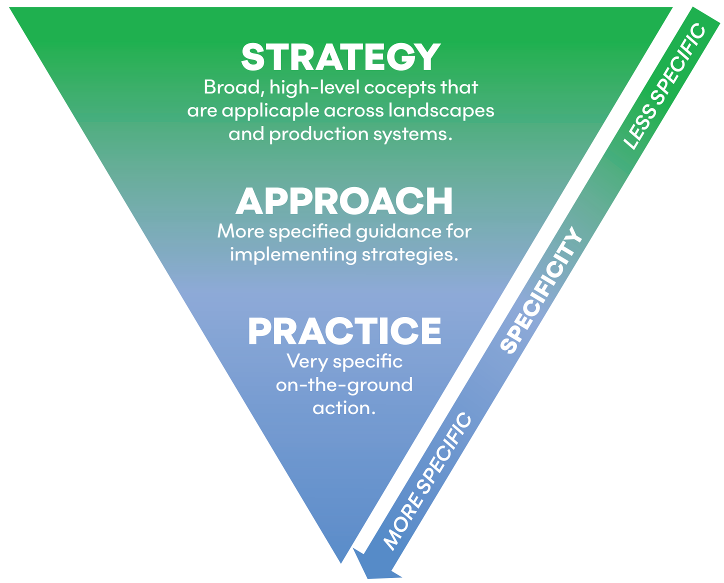


Figure 6. The adaptation menu offers a hierarchical organization that provides high-level strategies as a starting point, with more specific approaches and practices therein to guide the process of adaptive management planning from concept to action.

THIS MENU DOES

- Provide a starting point for exploring and identifying a range of potential actions to support on-farm adaptation.
- Help producers meet their management goals and objectives in light of climate change.
- Provide examples of practices that can be used to implement producer-prioritized climate adaptation strategies.

THIS MENU DOES NOT

- Make specific management recommendations.
- Prioritize or give preference to any particular strategy, approach, or practice. Many factors will determine what is best for your operation.
- Provide an exhaustive list of all possible practices for meeting strategic climate adaptation goals and objectives.

Box 3. Menu of Adaptation Strategies and Approaches for California Specialty Crops

Strategy 1: Support and Maintain Soil Health, Soil Biological Services, and Water Quality

Approach 1.1: Maintain and Improve Soil Structure

Approach 1.2: Enhance Soil Biology and Nutrient Availability with Organic Amendments

Approach 1.3: Manage for Soil and Water Salinization

Approach 1.4: Manage Fertilizer Application to Protect Groundwater Quality and Soil Health

Strategy 2: Cope with Uncertain Water Availability

Approach 2.1: Improve or Alter Water Systems to Meet Current and Expected Future Demands

Approach 2.2: Manage for the Effects of Drought

Approach 2.3: Prepare for Changing Patterns of Precipitation

Strategy 3: Manage Biological Crop Stressors

Approach 3.1: Reduce Pest Pressure

Approach 3.2: Reduce Disease Risk from Pathogens

Approach 3.3: Reduce Weed and Invasive Plant Pressure

Strategy 4: Prepare for Temperature Change

Approach 4.1: Adapt to Warmer Conditions

Approach 4.2: Manage for Changing Seasonality

Approach 4.3: Prepare for Longer-Term and Larger-Scale Temperature Changes

Strategy 5: Enhance Preparedness for Extreme Events

Approach 5.1: Prepare for Extreme Heat Events

Approach 5.2: Manage for Extreme Precipitation and Flooding

Approach 5.3: Enhance Resilience to Extreme Wind

Approach 5.4: Prepare for and Respond to Wildland Fire and Smoke Impacts

Strategy 6: Manage Farms and Fields as Part of a Larger Landscape

Approach 6.1: Integrate, Improve, or Maintain Natural Ecosystems within Agricultural Operations

Approach 6.2: Promote Biological Diversity Across the Landscape

Approach 6.3: Conserve Individual Farms

Strategy 7: Develop or Expand Co-Benefit Efforts to Mitigate Climate Change

Approach 7.1: Reduce On-Farm Greenhouse Gas Emissions

Approach 7.2: Increase On-Farm Soil Carbon Sequestration

STEP 4 PUT IT INTO PRACTICE

In **STEP 4** you have an opportunity to consider and identify the adaptation **strategies, approaches, and practices** that will help you realize your goals and objectives while accounting for the effects of climate change.

Use the **menu outline** in Box 3 above to help you narrow down your list of potential actions. Refer to the **detailed menu** provided after Step 5 to learn more about the importance of each strategy and approach, and see some example practices that can be put into place. Once you have identified a few adaptation options, you can use this template to organize and record your thoughts.

Management Goals and Objectives: Consider your revised goals and objectives from Step 3, if applicable.
Challenge or Vulnerability: What climate challenge or vulnerability are you addressing?
Current Strategies, Approaches, and Practices: Are there any strategies, approaches, and/or practices that you have previously implemented? What challenge/vulnerability were they addressing, and did they help you to meet your management goals and objectives?
New Strategy, Approach, and Practice: Which strategy, approach, and practice(s) have you selected to address the identified challenge/vulnerability and help you meet your management goals and objectives? Remember, the menu does not provide an exhaustive list of all possible adaptive actions that you can take!
Benefits: What benefits and/or opportunities could your selected approach and practice(s) provide? On what time scales?
Current Drawbacks and Barriers: If you have previously implemented climate-smart strategies, approaches, or practices, what drawbacks or barriers have you faced? How did you overcome those barriers?
New Drawbacks and Barriers: What drawbacks or barriers might you face in adopting the selected approach and practice(s)? How might those barriers be overcome?

STEP 5 MONITOR AND EVALUATE

After implementing one or more adaptation practices, it is important to **monitor and evaluate** the effectiveness of those actions in order to ensure long-term success. This step in the adaptation process is about identifying and reflecting on questions that will help determine whether the implemented practices are supporting the farm management goals and objectives, or if adjustments should be made. A monitoring plan can also help producers decide whether various approaches should be prioritized or additional practices executed as new climate observations are made, as new information or resources become available, or as long-term farm management goals change.

Some considerations when developing a monitoring plan include:

- What will be monitored to assess effectiveness? Depending on the practice enacted, this could be variables like soil characteristics, water use, or crop damages.
- How will you measure these indicators of effectiveness?
- When, where, and how often will you measure your indicators?
- What is your threshold for success? In other words, by how much do you want to increase soil health measures, curb water use, or reduce crop damages?
- Do you have the information and tools you need in order to carry out the monitoring and take your measurements?

Making sure that a monitoring plan is feasible – in terms of time, cost, and effort – is a key to its success.

When evaluating the results of your monitoring efforts, consider these questions:

- Have I met my threshold for success? Or am I at least trending in the right direction?
- Are the implemented practices helping me to achieve my management goals?
- Do my monitoring observations indicate that my management objectives should be re-evaluated?
- Am I still monitoring the most useful indicators, and do previously adopted practices still fit within my *current* farm management plan?

Regular and consistent evaluation of management plans and implemented adaptation practices is crucial in helping farms adapt to a changing climate.

STEP 5 PUT IT INTO PRACTICE

In **STEP 5** you are tasked with developing a **monitoring and evaluation (M&E)** plan to assess the effectiveness of the adaptation action(s) you selected in Step 4. Although you will not *carry out* your M&E plan until after you have implemented your action(s), thinking carefully about the M&E process or developing a plan prior to enacting on-farm changes may be useful for identifying the potential limitations and ensuring that your chosen action(s) are justifiable in the long term.

For developing your M&E plan, use the **MONITORING WORKSHEET** below.

Action(s) or Practice(s):
Measurable Indicator: Choose one. It can be general, such as farm water use, or specific, such as soil infiltration rates.
Tools and Methods: How will you monitor for change?
Schedule: When will you monitor?
Sites: Where will you monitor, and how will the sites be marked?
Name and Cost of Lab Analyses or Tools:
Baseline: Refer back to Step 1 if needed. If measurements have not been taken yet, is there time to do so before implementing your action(s) or practice(s)?
Interpretation: What outside information or help will you need to interpret the results?
Accuracy: In general, how accurate is the measurement method? How "noisy" or variable is the indicator, year-to-year or site-to-site? How many measurements are recommended in each round?
Target: What is your numeric threshold for success?
Time Scale: When do you expect to reach your numeric target?

Once you have successfully enacted your monitoring plan, use the **EVALUATION WORKSHEET** below to assess whether your actions have helped to achieve your goals and objectives. Farmers who have already been engaging in adaptation practices can also benefit from addressing these evaluation questions.

Progress Towards Adaptation Goals: In what ways are your actions helping you to achieve your management goals?
Updating Whole-Farm Adaptation Goals: How have the outcomes of this adaptation action changed your farm management goals and objectives?
Reaching Target(s): How have your indicators progressed in comparison to the thresholds for success?
Other Indicators or Methods of Measurement: Can other indicators be useful? How about different measurement methods for the established indicators? Are new measurement technologies or cheaper measurement methods available?
Improving Practice(s) Effectiveness: Are there any changes that you can make to improve the effectiveness or efficiency of your implemented action(s) or practice(s)?
Maintenance of Practice(s): How consistently, and how intensely, do your action(s) or practice(s) need to be implemented going forward in order to meet your goals?
Next Steps: How can you further advance your farm management plan and adaptation needs? Are there actions that should be expanded, or complementary practices that can be adopted?

A Menu of Adaptation Strategies and Approaches for California Specialty Crops

Strategy 1: Support and Maintain Soil Health, Soil Biological Services, and Water Quality

Healthy soils support the productivity and profitability of diverse agricultural enterprises, and they regulate water quality and quantity while providing for many agronomic functions and ecosystem services.[20,21] These functions and services depend on the physical, chemical, and biological properties of the soil, some of which are dynamic and easily altered (e.g., soil biodiversity and structure), while others are inherent or more resistant to change (e.g., soil texture and color). Unfortunately, climate change creates multiple direct and indirect threats to soil health, such as disruption of soil structure from extreme weather events,[22] decreased soil microbial diversity,[23] and soil and water salinization.[24] To buffer against these climatic impacts, producers may consider adaptive management approaches and practices such as those listed below.

Approach 1.1: Maintain and Improve Soil Structure

Soil structure results from the aggregation of soil particles, which is strongly dependent on particle size distribution ("texture"), charge-based attraction between clay particles, and organic "glues." Well-structured soils are those that have a better ability to draw in (infiltrate) and store water, to support microbial activity, and to support root health. They remain more stable under pressure, are easier to till, and can require less tillage. When the structure is promoted, the soil's functions can better withstand conditions like drought and extreme precipitation (see also Strategies 2 and 5).

Soil structure can be maintained and even improved through practices that increase soil organic matter; practices that protect soils from rain impacts, wind erosion, and heating; or practices that reduce tillage and the additional loss of carbon that comes with the break-up of aggregated soil particles.[25] For example, minimum tillage with the retention of residues reduces the amount of soil lost to storm runoff and also reduces evaporative water loss from the soil surface.[26] Alternatively, cover crop rotations may require some degree of tillage, but they can shield the soil from rain, improve drainage, and re-build degraded soils.[26]

Examples of adaptation practices include:

- **Practice 1.1.1: Minimize or eliminate tillage** and other traffic to improve soil structure and fertility, ideally retaining residues as well.[27,28,29]
- **Practice 1.1.2: Include selected cover crops in field rotations or in orchard alleys** to protect soil, break up compacted layers,[30] produce channels for water that maximize infiltration, water storage, and irrigation water use efficiency,[31] and contribute carbon exudates for promoting microbial activity and soil aggregation.
- **Practice 1.1.3: Implement reduced-till cover cropping** by mowing, flaming and/or adding herbicide to avoid additional disking or disruption. Shallow disking or direct seeding may be adequate for establishment.[32]
- **Practice 1.1.4: Promote healthy root growth** through practices such as optimizing irrigation and nutrient placement, or applying compost teas,[33] humic acids,[34] mycorrhizal inoculations when useful,[35] and gypsum amendments on saline soils.[36]

Approach 1.2: Enhance Soil Biology and Nutrient Availability with Organic Amendments

Soil biological processes are considered to be the basis of health and functionality in any agricultural system,[37] so it is vital to maintain a suitable environment for soil microorganisms in all farming systems. At the same time, climate change is expected to have both direct and indirect negative impacts on certain soil biological processes,[38] soil biodiversity,[39] and soil health generally.[40,41] As a result, some studies suggest that climate change will decrease surface soil organic matter,[42] with impacts on fertility and biodiversity.[39]

Organic amendments have been applied to cropped soils for millennia,[43] serving to restore some of the biological and nutrient cycles that are interrupted by the harvesting of crops. They contain nutrients and carbon substrates that microorganisms use for energy. The metabolic activity of soil microbes produces polysaccharides that act as organic soil "glues," which help soil particles to form stable aggregates and retain nutrients through charge interactions. Organic amendments can thereby increase the rates of nutrient cycles, provide macro- and micro-nutrients, and increase soil biodiversity, and thus they can have benefits for pest and pathogen control,[44] and for enhanced crop production.[45]

The selection of suitable organic amendments depends on soil type, cropping system, and irrigation practices. Growers may be well advised to undertake soil sampling in order to understand the specific composition and condition of their soil.

Examples of adaptation practices include:

- **Practice 1.2.1: Apply compost**[46]while paying attention to its feedstocks, nutrient contents, and pathogenic analyses where relevant, to build up the organic matter and its functions in the soil.
- **Practice 1.2.2: Apply a surface mulch** of wood chips, straw, or greenwaste to help reduce evaporation, suppress weeds, and build soil organic matter over time.[47,48] Greenwaste mulches should always be checked against food safety requirements.
- **Practice 1.2.3: Apply manure (fresh, slurry, compressed, pelletized, or composted)** to supply soil with nitrogen, phosphorus, and micronutrients.[49] Check food safety requirements.
- **Practice 1.2.4: Retain crop residues, or allow animals to graze them**, which will return nutrients and organic matter to the soil through digestion and decomposition.
- **Practice 1.2.5: Consider undertaking Whole Orchard Recycling (WOR).** WOR incorporates large amounts of wood chips into the soil to improve soil functions including nutrient uptake, aggregation, and water retention.[50] Crop nitrogen needs may be moderately higher for a few years after incorporation, as the wood chip decomposition process creates a sink for nitrogen.[51]
- **Practice 1.2.6: Incorporate biochar into the soil** to retain nutrients[52] and increase carbon, among other possible benefits. The specific feedstock and preparation strongly affect its performance as do the properties of the soil to be amended.
- **Practice 1.2.7: Incorporate cover crop rotations** into both annual and perennial systems[53] to boost productivity while providing organic matter, capturing nutrients that could otherwise leach out of the soil, and fixing nitrogen by using leguminous covers.

Whole Orchard Recycling at Rock'N Almonds

Whole Orchard Recycling (WOR) is the practice of grinding whole trees into chips once they have reached the end of their agronomic lifecycle. Incorporating these chips into the soil can **increase soil organic matter, improve water holding capacity, and increase yield**. Seeing the benefits of this practice can take anywhere from 2-5 years, but adopters say it is worth the wait.

Rock'N Almonds needed a practice that would work for them long term as they operate in the Central Valley, an area prone to sustained drought and extreme heat. So, in 2015 they started incorporating WOR on a block of their orchard. They first cut down and chipped up trees that had reached the end of their lifecycle and incorporated the chips into the soil. After letting the material break down for about 2 years, they planted new trees.

In comparison to their conventionally managed blocks, **they found the WOR block soil to have higher organic matter and carbon content, and enhanced water holding capacity.** Together, these benefits helped Rock'N Almonds increase yield and cut down on labor cost, which helped them reach their management goals of remaining profitable.

See more info on Whole Orchard Recycling in California here!

Approach 1.3: Manage for Soil and Water Salinization

As water supplies in California have constricted, irrigation water quality and soil salinity have worsened. When surface water is limited, the increased use of groundwater for irrigation can exacerbate salinity issues in some locations, depending on the salinity of the groundwater. Increases in soil salinity can create plant water stress, requiring more irrigation for crop needs and for leaching fractions.[54] Drainage management is also critical for managing salts in certain soils. This is seen in parts of the Delta and in the western San Joaquin Valley, where saline water tables that extend up to the root zone have aggravated the effects of naturally high soil salinity.[55] Increased soil salinization can have detrimental impacts on crop yield[56] and crop quality.[57] Certain specialty crops, including vegetables, are especially vulnerable to soil and water salinization.[58] This poses a particular problem in the vegetable-producing coastal areas where groundwater depletion has increased saltwater intrusion into groundwater aquifers.[59] Under climate change and in the absence of adaptive action, California producers can expect increasing salinization challenges.[24] Fortunately, proper soil and irrigation management techniques at the field level, such as the practices listed below, can ameliorate some of the impacts of salinization. Prior to enacting these practices, consider soil and irrigation water testing by a reputable lab to guide your management decisions.

Examples of adaptation practices include:

- **Practice 1.3.1: Test irrigation water sources and agricultural soils** for specific salt species and levels. Many laboratories will make corresponding management recommendations.
- **Practice 1.3.2: Monitor plant symptoms and salt levels in annual tissues or leaves.** In specialty crops, leaf sampling for nutrient levels is a complementary tool, following UCANR critical thresholds[60] and sampling protocols.[61,62]
- **Practice 1.3.3: Consider the salt contents in fertilizers before application**, making note of existing soil solution salinity levels and sodium absorption ratio testing.[63]
- **Practice 1.3.4: Reposition driplines, reschedule irrigations, or shift irrigation methods** to address localized salinization.[64,65,66]
- **Practice 1.3.5: In groundwater-dependent areas, consider annual maintenance leaching**, especially when growing vegetables.[67,68] In California, farmers may be able to use floodwaters through field-based ***"managed aquifer recharge" (Flood-MAR). In other cases, timing a leaching fraction after major winter rains increases its effectiveness.***
- **Practice 1.3.6: Where practical, consider installing tile drains** to extract saline leaching water and prevent further salinization of groundwater.
- **Practice 1.3.7: Consider applying compost** to improve water uptake and nutrient availability in saline soils.[69] The salt contents of any applied compost should be assessed before use. For example, manure composts typically have higher salts, while greenwaste composts have less.


Applying compost to soils can improve their water holding capacity and nutrient availability.

Approach 1.4: Manage Fertilizer Application to Protect Groundwater Quality and Soil Health

Groundwater is a vital component of California's water supply, with 40% of California's urban and agricultural areas relying on groundwater resources,[70] especially in times of drought[71] (see Strategy 2 for more on drought). Agricultural intensification has significantly increased food production since the mid-20th century. Unfortunately, the increased fertilizer application also increased the hazards for the state's water resources, including groundwater. Inefficiencies in nutrient cycling and crop use of applied nutrients can allow elements from the fertilizers and manure such as sodium, chloride, and nitrogen to reach groundwater, causing salinization, diminished soil health, and threats to human health.[72] Improved nutrient and water management in recent decades has reduced agriculture's impacts on groundwater, and it is important to build upon those gains.

Focusing on nitrogen (N), which has the most complex cycle of any applied nutrient, excessive applications of N can allow bacteria to oxidize and consume soil organic matter.[73] On the other hand, if adequate N is not provided, crops may "mine the soil" by consuming N from soil organic matter, and thus degrading that organic matter over the long term.[74] Efforts to apply nitrogen accurately in California have found that irrigating with groundwater that has high nitrate levels can upset crop development, delay maturity, and reduce yield,[75,76] so the background nitrate content of groundwater should be taken into account.

Fortunately, adaptive water-saving technologies also allow more precise applications of fertilizer to best match the 4 R's of nutrient management – the Right Amount, at the Right Time (coinciding with crop uptake), in the Right Form, and in the Right Place. These refinements in fertility management reduce the risk of moving nutrients below the rooting zone, where they are out of reach of crop roots and pose a nutrient loading hazard to groundwater.

Examples of adaptation practices include:

- **Practice 1.4.1: Develop a nitrogen (N) budget.** A table of N inputs including soil and water N, and exports including likely gaseous and leaching losses, can form the basis of efficient fertilization. Farmer-oriented computational tools are also available and they are becoming widely used for compliance and management.
- **Practice 1.4.2: Monitor soil and plant N levels during the growing season.** Soil nitrogen "quick tests" can be performed by farm staff without extensive training,[77] while monitoring leaf N concentrations is a useful tool in many specialty crops.[63]
- **Practice 1.4.3: Manage N** applications to avoid spiking N in the soil beyond the crop's uptake capacity. Particularly on sandy soils, or soils with low organic matter, it may be important to change the N fertilizer formulation, change the frequency of N applications, consider controlled-release fertilizers or nitrification inhibitors, or even add biochar to the soil, which can retain N.[78]
- **Practice 1.4.4: Optimize the use of fertigation** considering fertilizer formulation, high-frequency application, emitter placement, and the timing of fertilizer injection within the irrigation set, to place N at the root depth in the soil and avoid leaching.[79]
- **Practice 1.4.5: Manage manure applications** by considering likely decomposition and N mineralization rates, as well as the contents of various nutrients. A wide range of salts and nutrients found in manure can affect groundwater quality, especially if their release does not correspond to crop needs.

Strategy 2: Cope with Uncertain Water Availability

Adequate water resources are imperative for agricultural production. While sensitive to the seasonal and year-to-year variability of the state's Mediterranean climate, California's extensive water infrastructure supports the state's expansive agricultural sector and has buffered it from in-season water shortages. However, even with the most elaborate water conveyance and storage system on earth, the state's water resources will be challenged to keep pace with the changing water needs driven by climate change. Production systems will need to endure increasing frequencies of both droughts and very wet years, as projected under future conditions.[80,4] Such changes in water availability can have severe consequences for agricultural production if not properly managed. Outlined below are a series of approaches, each with examples of practices, that can aid in managing for and coping with uncertain water availability.

Approach 2.1: Improve or Alter Water Systems to Meet Current and Expected Future Demands

Approximately three quarters of California's cropland is irrigated, with more than one third of irrigated acreage producing high-value perennial fruits and nuts.[81] Crop production in California uses more than 25 million acre feet of irrigation water per year, accounting for between 40%-60% of the state's total water supplies.[82] Climate change is expected to increase agricultural water use as warmer temperatures increase crop transpiration rates and evaporation losses reduce available soil moisture. Across California's agricultural lands, climate change is projected to increase summer reference evapotranspiration by ~5-15% over historical averages by the end of the 21st century.[83] Likewise, warming temperatures will reduce snowpack and decrease runoff during the summer growing season, reducing surface water availability.[2] The warming-driven increases in water demand coupled with decreases in water availability will require the refinement of on-farm water management to optimize water use efficiency.

In recent decades, upgrades to irrigation systems have been shown to reduce irrigation water usage in some Mediterranean climates.[84] In order to be resilient against future conditions, irrigation systems will likely need to be altered with innovative methods that increase infiltration and enhance water use efficiency.[85] For example, when more efficient on-farm irrigation infrastructure is installed, irrigation water use typically decreases; however, under future conditions, California farmers may need to upgrade or enhance more than 30% of their irrigation infrastructure to maintain or reduce irrigation use below recent levels.[86] These alterations will provide a critical buffer, allowing irrigation to continue during future water-restricted years. The following practices provide examples for updating or enhancing irrigation systems to adapt to current and expected future water demands.

Examples of adaptation practices include:

- **Practice 2.1.1: Update existing irrigation infrastructure to improve irrigation efficiency.**[87,88] For example, install irrigation blocks that follow soil type where possible and consider hybrid approaches such as combining subsurface drip and furrow.
- **Practice 2.1.2: Maintain irrigation systems for optimum performance and distribution uniformity.** Maintenance is also important for fertigation systems.
- **Practice 2.1.3: Consider adopting or expanding irrigation technology use.** Advances in soil moisture sensors, cloud computing, and estimates of field-scale ET via surface renewal and remote sensing approaches provide opportunities to improve water use efficiency and optimize irrigation scheduling.[89]
- **Practice 2.1.4: Create a water budget to better assess water demands.** Using a water budget tool can help measure the efficiency and regional suitability for the amount of water applied to a landscape based on local climate data.[90]

Minimum Till at Full Belly Farm

Full Belly Farm is a diverse, 400-acre farm in Yolo County's Capay Valley, where more than 80 different crops are produced. One of the projected impacts of climate change to Full Belly's operation is an increase in the frequency and severity of drought. The managers at Full Belly Farm have adopted **minimum till practices** to support their farm management objectives for maintaining soil health and their long-term goals of resilience and sustainability.

Minimum tillage avoids unnecessary disruption of the soil while allowing for crop-specific needs, such as shallow intrusions for planting. This practice **improves soil health** in the short term and increases the soil's ability to **hold onto water** in the longer term, which can enhance the farm's ability to **bounce back from events like drought**.

Full Belly Farm's minimum till practices include rolling down cover crops and moving residue to create space for planting vegetables with minimal soil disturbance. Despite the added labor in managing weed pressure, Full Belly believes **the benefits of minimum till outweigh the costs**, and the farm is undertaking other minimum till experiments with the goal of expanding this practice across the farm.

Check out this University of California video on Minimum Tillage Systems!

Approach 2.2: Manage for the Effects of Drought

Periodic drought is the norm rather than the exception in California. Drought can challenge a grower's ability to meet crop water demands. Increased water stress can slow plant development, reduce nutrient uptake, decrease crop yield, and in extreme cases kill much of the crop.[2] Climate change is expected to increase the risk of drought (including multi-year and multi-decadal droughts) as warmer temperatures drive higher evaporation rates and increase the atmospheric water holding capacity.[91,92,93] These 'hot droughts' can be especially pernicious, as the decreased soil moisture serves to increase soil temperatures and raise surface-level air temperatures, creating a positive feedback loop that can deepen existing drought conditions.[94] Such changes make it imperative that producers carefully manage drought conditions.

In recent decades, growers have primarily used groundwater to lessen the effects of decreased surface water availability,[95] and in recent years, groundwater demand during drought has been growing due to the expanded acreage of perennial crops. Subsidence, overdraft, and changes in water flow patterns may challenge the capacity of groundwater to safeguard against future drought.[95] Management practices such as those that improve soil health and soil water holding capacity (Approaches 1.1 and 1.2) or increase irrigation efficiency (Approach 2.1) can provide a buffer against drought impacts. California producers may wish to consider multiple adaptive practices to enhance their resilience.

Examples of adaptation practices include:

- **Practice 2.2.1: Employ reduced tillage, cover cropping, and organic amendment practices to reduce soil water evaporation[47] and improve water infiltration and retention.**[96] *Note that reduced tillage may increase weed pressure (see Approach 3.3 for information on weed pressure). Cover cropping opportunities may be limited in some systems (see Approach 1.1 for more on BMPs for soil).
- **Practice 2.2.2: Utilize deficit irrigation strategies** to balance production goals with available water resources during drought. This practice works best with tree crops and vines.[97,98,99]
- **Practice 2.2.3: Plant drought tolerant varieties[100] and/or shift to drought resistant rootstocks**[101] to maintain or enable crop production where water is scarce (see Approach 4.3 for more information on incorporating new varieties).
- **Practice 2.2.4: Adopt conservation-oriented irrigation scheduling practices** such as soil moisture monitoring, evapotranspiration (ET) scheduling, and plant-based irrigation scheduling using temperature or water potential monitoring.[102]

Approach 2.3: Prepare for Changing Patterns of Precipitation

California has historically received ~75% of its annual precipitation between November and March,[103] with more than 30% of the state's annual precipitation stemming from atmospheric river storms.[104] Observed daily precipitation patterns across the Western U.S. show increasing durations between precipitation events[105], and climate models project increasing year-to-year variability of atmospheric river storms[106] and a shortening of California's wet season.[107] Precipitation timing can strongly influence management decisions such as planning field work, weed and pest management, and spray regimes.[108] Challenges resulting from changing precipitation patterns can be ameliorated with proper management. For example, during unusually wet periods, growers may prepare for later needs using water catchment systems and management plans that aid aquifer recharge (e.g., flooding of orchard crops during the dormant season[109]). As climate change alters the timing of the wet season and increases the likelihood of large swings in annual precipitation extremes,[4] the adoption of on-farm recharge efforts, including optimizing infiltration and minimizing runoff, as well as the refinement of irrigation water use efficiency, will be essential. Additional practices for adapting to changing precipitation patterns can be found in Approach 5.2.

Examples of adaptation practices include:

- **Practice 2.3.1: Incorporate swales into the landscape to slow the movement of water.**[96] Swales can reduce soil erosion (Strategy 1) and encourage water infiltration into soils, providing a buffer against drought.
- **Practice 2.3.2: Use retained stubble/residues or mulch** to protect the soil surface and prevent soil crusting, resulting in reduced runoff.[28] Residues can also support soil health and soil water retention (see Approach 1.2). However, they may not be appropriate in some vegetable systems.
- **Practice 2.3.3: Carry out annual cropping, cover cropping, or other plantings on temporarily fallowed land** to support soil health, which can increase soil water holding.
- **Practice 2.3.4: Implement agricultural managed aquifer recharge (AgMAR)** to increase groundwater recharge and counteract groundwater overdraft.[110,111] Leave flood infrastructure intact in areas where surface water deliveries may allow groundwater recharge in the future.[87]

Allowing fallowed fields or flood-tolerant crops to absorb excess rainwater can encourage groundwater recharge.

Strategy 3: Manage Biological Crop Stressors

Due to the direct impact of temperature on the growth and life cycles of various biological stressors of crops (e.g., insects and weeds), observed and projected increases in temperature will have significant implications for agricultural systems.[2] Agricultural insects and diseases account for a large percentage of crop yield damages every year,[112] while weeds can stress plants by competing for water and nutrient uptake. Under climate change, insect,[113] disease,[114] and weed pressures[115] are projected to increase, requiring changes in pest and weed management systems. In order to alleviate some of the risks associated with biological stressors, it is critically important to consider related best management approaches in farm operations and planning.

Approach 3.1: Reduce Pest Pressure

Because insect pests are cold-blooded, their growth rates and lifecycles are largely regulated by weather conditions and can increase as temperatures rise.[116,117] California's agricultural sector has already seen shifts in pest pressure, due in part to warmer average temperatures.[2] The continuation of warming temperatures driven by climate change are projected to alter insect migrations and developmental rates, and increase the number of pest generations born each year.[113,118] Warmer temperatures can also increase insect outbreaks,[119] and lead to the occurrence of new non-native pests affecting crops.[2] Reducing pest pressure will require the implementation of both preventive as well as control measures, and given the economic impacts of pest damages,[113,120] producers should take an active role in implementing improved pest management practices.

Examples of adaptation practices include:

- **Practice 3.1.1: Follow the latest integrated pest management guidelines** using Prevention, Avoidance, Monitoring, and Suppression (PAMS) strategies to optimize pest management. Implement preventive and control measures, such as choosing varieties adapted to current conditions; optimizing nutrient and water management; removing diseased plant material or pest host material (e.g., sanitizing nut orchards during the winter); harvesting crops early to minimize pest damage risk; disrupting pest mating (e.g., by pheromones or sterile insect release); and biological control.[121,122,123]
- **Practice 3.1.2: Create an environment that is inhospitable for the pests** by employing soil solarization, steam, and anaerobic soil disinfestation.[124]
- **Practice 3.1.3: Create habitat for beneficial insects that prey on agricultural pests and enhance natural enemy populations** through perennial hedgerows, wildflower areas, flowering islands, etc.[125,126]
- **Practice 3.1.4: Ensure that monitoring and scouting efforts during the season match current conditions** to effectively time insecticide applications for reducing pest pressure.

Crop pests, like this glassy-winged sharpshooter, require careful monitoring and following best management practices such as IPM practices to reduce crop damages.

Approach 3.2: Reduce Disease Risk from Pathogens

Plant pathogens are detrimental to crop health and pose a major threat to regional and global food supplies.[127] Globally, a warming-driven poleward expansion of crop pathogens has been observed.[128] In California, more than $34 million in indemnity payments have been made to farmers due to pathogen losses since 1989, with an apparent positive trend in indemnity claims and the three most costly years occurring in the last decade according to AgRisk Viewer[112]. Increasing pathogen risk is expected under climate change, as warmer weather can influence the spread and emergence of many pathogens.[129] For example, warmer weather during the typically cool winter season can increase the prevalence of Pierce's Disease in grapevines.[130] Climate change may also reduce the occurrence of frosts in the future,[131] which could increase the risks and management challenges associated with pathogens and other biological crop stressors. While some of the impacts of pathogens associated with climate change might be inevitable, it is important to implement adaptive management practices to control and prevent pathogen spread as much as possible.

Examples of adaptation practices include:

- **Practice 3.2.1: Decrease pathogen spreading capability** by intercropping disease resistant and disease susceptible varieties.[132]
- **Practice 3.2.2: Include other intercropping strategies such as strip intercropping, row intercropping, relay intercropping, and intercropping of genetic variants** to reduce disease.[132]
- **Practice 3.2.3: Incorporate Biological Control Agents** that ecologically and environmentally reduce pathogen pressure.[133]
- **Practice 3.2.4: When possible, utilize early warning systems** for diseases.[134,135]
- **Practice 3.2.5: Use weather-based decision support tools** for monitoring and scheduling fungicide applications (e.g., Strawberry Advisory System; www.agroclimate.org).

Approach 3.3: Reduce Weed and Invasive Plant Pressure

Weather and climate have direct influences on weeds and invasive plants. Increasing temperatures, shifting precipitation patterns, and elevated CO_2 concentrations are expected to favor highly adaptive weeds and invasive plants.[136] In experimental trials, invasive plants in Mediterranean landscapes were shown to increase their reproductive output under projected climate change scenarios.[137] Similarly, weeds are expected to naturally adapt under a changing climate,[138] potentially allowing them to expand their ranges and compete with production agriculture for water and nutrient uptake.[115,139] In the absence of careful management, these pressures can severely impact crop growth and yield.[138] While herbicide application has historically been a successful means of mitigating weeds in agricultural settings, climate change is expected to reduce herbicide efficacies, which can be impacted by various environmental conditions.[140] Looking forward, reducing weed pressure and invasive plant pressure in agricultural systems is crucial. Provided below are a few examples of high-priority practices that could be implemented.

Examples of adaptation practices include:

- **Practice 3.3.1: Include cover crops** to reduce weed pressure and enhance soil quality[141] (see Approaches 1.1 and 1.2 for more on cover crops).
- **Practice 3.3.2: Discourage weed growth by intercropping multiple varieties in one planting area, rotating crops after each lifecycle, and altering plant densities between seasons**[132] (see Approach 4.3 for more on intercropping and rotating).
- **Practice 3.3.3: Select crop cultivars that are highly adapted to climate variability** through better light interception or water and nutrient uptake, which can provide better competition and allow the crops to outperform weed growth[115] (see Approach 4.3 for more on cultivar selection).
- **Practice 3.3.4: Change seeding rates, row spacing, and row direction** to manipulate weed growth and control.[138]
- **Practice 3.3.5: Survey farms in the fall and spring before the growing season to monitor weeds that escaped previous weed control efforts** and adjust the current weed management strategy to account for these weeds.[142]
- **Practice 3.3.6: Consider weed management before planting.** It is easier and cheaper to control perennial weeds before planting a perennial crop because there is a wider selection of treatment options available when the ground is fallow.[142]
- **Practice 3.3.7: Implement Integrated Weed Management,** a holistic approach to weed control (see the Resources section for crop-specific integrated weed management references).

Strategy 4: Prepare for Temperature Change

California's temperate climate, with warm summers and mild winters, has allowed high-value specialty crop production to thrive across much of the state. However, warming temperatures and shifting seasonality may challenge California specialty crop production by shifting planting patterns,[2] altering pollinator behavior,[143] lowering yields,[13] and increasing water demand (see Strategy 2). As a result, producers may wish to employ adaptive approaches to help ameliorate the impacts associated with rising temperatures. The approaches below address the effects of warming average temperatures, changes in the timing of annual temperature patterns, and future temperature conditions that may be outside of the temperature regime seen today.

Approach 4.1: Adapt to Warmer Conditions

Though extreme temperature conditions are receiving a great deal of attention (see Strategy 5), changes in average or baseline temperatures can also influence crop geography, phenology, and quality. Both cool and warm season temperature increases are important considerations for California's specialty crop industry. California has experienced notable warming trends since 1895, with recent decades having greater rates of warming,[2] and models project that climate change will further increase temperatures over the coming decades.[144] These warming trends will have numerous implications for California's specialty crop production. Warmer winter temperatures will reduce chill accumulation and subsequently reduce both yields and the suitable cultivation areas for some high-chill crops like walnuts and pistachios.[145] Similarly, warmer summer temperatures can result in more rapid crop development in crops like processing tomatoes,[146] and reduced quality and reductions in suitable cultivation areas for crops like tomatoes, cantaloupe, and carrots.[147]

The appropriate practices for addressing warming conditions will vary by geography, cropping system and planning time horizon. This Approach emphasizes practices that are useful for adapting crops in their current locations to warmer conditions, though additional efforts such as crop variety or species changes may be required over longer time horizons (see Approach 4.3 below). Additionally, while warmer summer temperatures will increase water demand[86] and spur producers to employ practices that address irrigation (see Strategy 2), here we highlight non-irrigation management practices.

Examples of adaptation practices include:

- **Practice 4.1.1: Apply kaolin clay and/or dormant oil to nut crops to increase chill accumulation.**[148] The application of kaolin clay is most useful during sunny winters.[149]
- **Practice 4.1.2: Where possible, use chill portions to calculate winter chill.** Chill portions have been shown to better reflect crop phenology in California.[150]
- **Practice 4.1.3: Assess the need for earlier planting dates to avoid summer heat exposure** using localized, short-term summer warming projections.[151]
- **Practice 4.1.4: Prune the canopy or apply reflectants to reduce crop surface temperature.** Also consider incorporating plastic films, shade cloth, or netting to increase shade.[152,153]
- **Practice 4.1.5: Include cover crops to reduce soil temperatures**[154] where appropriate. *Note that cover crops may not be suitable for all operations, they may compete with primary crops for water and nutrients, and in some circumstances, they may increase pest pressure.
- **Practice 4.1.6: Incorporate agrivoltaics into agricultural systems** to cool the vegetative understory and allow for longer retention times of irrigation water within the soil.[155] This practice has an added benefit of providing renewable energy for the operation (see Strategy 7 for more information).

Agrivoltaics can provide dual benefits of shade for crops and on-farm renewable energy generation, offering opportunities for climate change adaptation and mitigation.

Approach 4.2: Manage for Changing Seasonality

Crop phenology, like other farm management decisions, is governed by the timing of the seasons. However, climate change threatens to alter the seasonality on which California's agricultural clock has been based. This Approach emphasizes changing springtime temperatures, though fall temperature changes have been observed[2] and projected,[156] and the implications of fall season changes are noted in Strategies 2, 3, and 5 while the changing seasonality of precipitation is addressed in Strategy 2.

Since the end of the 20th century, spring temperatures, as indicated by the date at which snowmelt is initiated, have arrived on average three weeks earlier than historic records.[157] Earlier and warmer springs have implications for water resources (see Strategy 2) and can result in earlier budbreak and bloom, which can increase the risk of frost damage[158] and may cause a mismatch between plant growth and pollinator activity.[159] Likewise, warming spring temperatures can compress the pollination windows in crops like almonds[160] and processing tomatoes,[146] and may decrease harvested fruit size in peaches.[161] Although producers may see some benefits from warming spring temperatures in the long term, the potential negative outcomes seem to require multiple avenues of adaptation in order to improve the resilience of existing crop systems. Adaptive actions to changing seasonality may involve water resources and pest management (see Strategies 2 and 3, respectively), as well as management practices to address warming spring temperatures such as those in the following examples.

Examples of adaptation practices include:

- **Practice 4.2.1: Manage cover crops** to support and diversify wild pollinator populations.[162,163]
- **Practice 4.2.2: Invest in infrastructure such as wind machines and sprinklers** to protect specialty crops from frost.[153] Consider that frost risk will ultimately decline under climate change projections[131] but in some areas it may remain a sufficient risk to warrant mitigation investments. Also consider local water use ordinances/policies and drought status when using sprinklers for non-irrigation activities.
- **Practice 4.2.3: Adjust transplant dates** depending on local in-season[146] and long-term[164] temperature projections.

Approach 4.3: Prepare for Longer-Term and Larger-Scale Temperature Changes

Temperature is a key driver of crop geography, and the temperature regime is a primary determinant of which crops would be most suitable for a particular area. Climate change projections also suggest that crops like carrots, tomatoes, and cantaloupes[147] may see declining suitability within their current cultivation ranges and northward shifts in their growing regions. This Approach focuses on practices that provide adaptive capacity for changing temperature regimes that are increasingly outside the bounds of current conditions. These practices include crop diversification and, potentially, transition.

Diversification is a risk management method that reduces operational exposure to the particular vulnerabilities associated with any one cropping system. Additionally, agroecosystems thrive on diversification, especially given changing climate regimes. By diversifying, producers can improve their resilience and mitigate the risks associated with crop failure, pest outbreaks, and pathogen transmission.[165] Transition on agricultural lands may fall on a spectrum from shifting varieties of crops to moving toward non-agricultural land uses. Projected warming may provide opportunities for incorporating novel crops or varieties where they were previously less suitable, providing a strategy for both improved resilience and longer-term adaptation.[166,167] Producers may begin with diversifying crop varieties or species as a means to incrementally transition to new crops that are better matched with the projected climate.

Examples of adaptation practices include:

- **Practice 4.3.1: Incorporate intercropping into annual systems** to achieve diversification benefits without compromising market value.[168,169]
- **Practice 4.3.2: Consider adopting products or markets that can utilize imperfect produce.**[96] For example, creating value-added products such as juices or jams provides operational diversification.
- **Practice 4.3.3: Transition to lower-chill cultivars** for fruit and nut crops impacted by reduced chill hours, as available.[170]
- **Practice 4.3.4: Transition to more heat-tolerant varieties** via repositories, genetic modification, or selective breeding.[165]
- **Practice 4.3.5: Transition to or incorporate mixed or alternative land uses** (e.g., conservation or energy production) to better align land use with climate conditions. See Strategy 6 for more information.

Strategy 5: Enhance Preparedness for Extreme Events

Extreme climate events can cause not only immense short-term damage but also long-term change,[171] and they can cause more severe impacts than non-extreme events. Climate change will increase the frequency, duration, and/or intensity of extreme events in California, including extreme heat,[7] extreme precipitation,[4,6] extreme wind,[172] and extreme wildfire events.[156] These events can have significant impacts on specialty crop production in California. For example, extreme heat can shift flowering times in perennials and create inhospitable growing conditions for many species,[173] and extreme precipitation can cause flooding, resulting in waterlogged soil and crop damage.[174] While producers may not be able to prevent these events outright, a number of approaches and practices can enhance preparedness and protect their operation.

Approach 5.1: Prepare for Extreme Heat Events

Extreme heat events can be a challenge for California agriculture, with impacts ranging from increased water demands and crop damage to loss of electrical power.[2] California's extreme heat events, which can be classified as either dry daytime or humid nighttime events,[175] increased at a rate of seven extreme heat days per year and 21 extreme heat nights per year over the 1987-2016 period.[103] However, climate change is projected to increase the frequency, intensity, and duration of extreme heat events across California, with regional variation in the degree of increase.[175,176]

Extreme heat events can have varying impacts depending on the cropping system, the tolerance of a given crop to heat stress, and the timing of the heat event. Crops tend to experience heat stress during the warm season, but anomalously warm spring temperatures can also harm crops like almonds, cherries, grapes, and pistachios.[7] Without proper preparation, extreme heat events can have deleterious consequences on specialty crop production including early flower drop and reduced pollen viability,[177] and decreased size, quality, and yield for multiple fruit and nut crops.[7] Similar adaptive management practices are applicable across cropping systems.

Examples of adaptation practices include:

- **Practice 5.1.1: Update irrigation scheduling in anticipation of a heat event.** (See Strategy 2 for more information on irrigation technology and scheduling.)
- **Practice 5.1.2: Add shade and/or shelter to modify the microclimate** with both natural (e.g., agroforestry) and/or man-made (e.g., tarps) methods.[178]
- **Practice 5.1.3: Establish soil cover using crop residues in orchard systems** to insulate the soil and roots from extreme heat.[178]
- **Practice 5.1.4: Shift to earlier planting dates to avoid summer heat stress.**[179] (See Approach 4.1 for more on shifting harvest dates.)
- **Practice 5.1.5: Switch to heat-tolerant varieties.**

Shade netting can provide sun protection for crops sensitive to heat. Netting may also provide protection from birds and hail.

Approach 5.2: Manage for Extreme Precipitation and Flooding

Extreme precipitation in California is often produced by atmospheric rivers (ARs), which are long, narrow streams in the atmosphere that carry large amounts of water vapor and can produce heavy rainfall.[180] In fact, almost all of California's major historical floods can be attributed to ARs.[104] Observations of daily precipitation across the Western U.S. show increased precipitation intensity,[105] and the occurrences of extreme precipitation events are projected to double in the future compared to their historical frequency in California,[80] accompanied by a decreased frequency of lower-intensity precipitation events. In addition, because climate change is increasing not only the intensity of extreme precipitation events[181] but also the duration and frequency of drought,[91,92] extreme precipitation events can occur after extreme dry periods, compounding the impacts to agricultural lands by exacerbating soil erosion and flooding.[182]

Agricultural impacts of extreme precipitation events can include crop damages and reduced crop quality,[183] increased soil erosion,[184] pollution from nutrient runoff, and pest infestation.[2,185] Additionally, given the increased flood risk, growers may consider adopting on-farm management practices to mitigate erosion and the potential damages from waterlogging and root rot. Additional adaptation practices applicable to extreme precipitation and flood management are provided in Approach 2.3.

Examples of adaptation practices include:

- **Practice 5.2.1: Incorporate tailwater pond(s) to capture runoff.**[186] Tailwater ponds can be particularly effective at reducing the sediment loss and pollution of neighboring downstream waterways.
- **Practice 5.2.2: Include cover crops in planting rotations to increase soil organic matter** and thus reduce erosion from extreme precipitation, encourage water absorption, and reduce soil crusting.[187]
- **Practice 5.2.3: Shift to flood-tolerant breeds and/or crop types.**[188,96] Flood-tolerant crops can also allow for the adoption of AgMAR practices during flood events to capture excess rainfall and adapt to changing precipitation patterns (see Approach 2.3).

Approach 5.3: Enhance Resilience to Extreme Wind

California's coastline is prone to strong and gusty winds due in part to the state's unique coastal topography and regional climate conditions, but the spatial and temporal distribution of the state's wind speed is expected to change with a warming climate.[172] While wind is a part of the climate in these coastal regions, an uptick in non-Santa Ana wind strength has been observed in the past 60 years.[189] Likewise, extreme Santa Ana events have also increased in intensity over recent decades.[190] Looking forward, summertime winds throughout the state are projected to increase in both frequency and strength, particularly in those coastal regions;[191] however, Santa Ana winds may decrease in frequency, if not intensity.[190] Current and future extreme wind events may impact agricultural systems in a number of ways. For example, extreme wind can cause or exacerbate erosion,[192] damage orchard trees,[193] and increase ignition risk and the spread of wildfires.[156] To protect against wind damages, growers may consider adopting practices that prevent erosion and reduce soil loss.

Examples of adaptation practices include:

- **Practice 5.3.1: Incorporate wind breaks in the form of tall, live barriers** such as hedgerows, fruit trees, or natural vegetation to provide shelter from wind and reduce erosion.[194]
- **Practice 5.3.2: Plant short-season crops or cover crops for high wind periods** to protect soil from wind.[195]
- **Practice 5.3.3: Consider measures such as speed control or polymer application** to control wind erosion and dust from unpaved roads.[196]

Approach 5.4: Prepare for and Respond to Wildland Fire and Smoke Impacts

Wildfires are a natural phenomenon in California and provide ecosystem services to parts of the state's forested land.[197] Multiple factors have led to an increase in wildfire frequency and severity in recent decades, with the state experiencing a fivefold increase in annual burned area from 1972-2018.[198] Climate models project that rising temperatures and related climatic factors will lead to a 36-74% increase in burned area by 2085,[199] and that extreme wildfire events (>10,000 hectares burned[199]) and extreme fire weather[156] will occur more frequently in the future. In addition, other climate-driven changes like shifts toward a later-onset wet season[200] and increasingly frequent hot and dry conditions[5,83] will increase wildfire risk.

Both wildfire flames and smoke impact California agriculture in unique ways. Wildfires can burn crops, destroy power lines and other vital infrastructure, and cause health problems for farm workers. For crops like winegrapes, smoke exposure can negatively impact fruit quality by causing smoke taint.[201,202] While there are limited field-level actions that can prevent wildfires, producers can make management changes to protect agricultural land and energy systems from the flames. This Approach emphasizes practices that prevent the spread of wildfire onto agricultural land and encourage energy security.

Examples of adaptation practices include:

- **Practice 5.4.1: Apply artificial grape cuticle to wine grapes one week before anticipated smoke exposure** to reduce the impact of smoke taint.[203]
- **Practice 5.4.2: Incorporate firebreaks into the agricultural landscape** to help protect land and crops from wildfire and reduce the possibility of fire spreading.[204]
- **Practice 5.4.3: Incorporate on-farm renewable energy into farm operations** to sustain production during power loss. See Approach 7.2 for more information regarding on-farm renewable energy.
- **Practice 5.4.4: Transition to crops that are less impacted by smoke.**

Strategy 6: Manage Farms and Fields as Part of a Larger Landscape

Individual farms influence and are influenced by the larger surrounding landscape and ecosystems within which they reside. While climate change impacts both farm and landscape-level systems, with purposeful management decisions that support ecosystem services, biological diversity, and the conservation of natural and working lands, farms can increase the resilience of the broader landscape and ameliorate the effects of climate change.[205] Encouraging management approaches and practices that focus on landscape-scale, agroecosystem-focused dynamics, such as the examples shown below, may help California's farms and fields adapt to climate change on a longer time horizon.

Approach 6.1: Integrate, Improve, or Maintain Natural Ecosystems within Agricultural Operations

The overall health and wellbeing of agricultural land is heavily influenced by the ecosystem of the surrounding landscape. As such, integrating, improving, and maintaining that ecosystem can help shield the lands that are in agricultural production from some of the negative effects associated with climate change.[206] Efforts that promote landscape function, connectivity, and diversity can support field-level adaptive capacity. For example, integrating and maintaining natural systems on farm field boundaries can support soil health and water quality.[207] Similarly, improving or maintaining vegetative strips, riparian buffers, or hedgerows can help to reduce water pollution[208] and support biological diversity, and they may increase the potential for soil carbon sequestration[209] (see Approach 6.2).

Developing and/or maintaining pollinator habitat through incorporating natural or semi-natural landcover or increasing crop diversity can provide benefits for the farm and the broader ecosystem. Here, pollinator habitat is maintained alongside solar panels, offering opportunities to manage the farm as a part of the larger landscape and contribute to climate change mitigation efforts by generating renewable energy.

Examples of adaptation practices include:

- **Practice 6.1.1: Maintain or restore riparian areas, wetlands, bottomlands, and floodplains.**[210,211]
- **Practice 6.1.2**: Plant a smaller portion of the land to **give natural ecosystem features such as streams the ability to move and adapt**.
- **Practice 6.1.3: Match landscapes and ecosystems with appropriate cropping patterns** to stay within the physical and productive potential of the land.[212]
- **Practice 6.1.4: Consider cultural cool season prescribed burns** of native vegetation to reduce the risk of catastrophic fire.[213]

Approach 6.2: Promote Biological Diversity Across the Landscape

Ecosystems are expected to experience biodiversity loss in the coming decades as a consequence of climate change,[214] meaning that promoting and maintaining biological diversity will be crucial to maintaining ecosystem balance.[186] In agricultural systems, diversity is often limited at the field scale. As such, supporting biological diversity at the landscape scale and improving diversity along the bounds of land in production can serve to support broader ecosystem function. For example, diversity-promoting management practices can support habitat for beneficial insects and wildlife. Moreover, many of the practices that producers can employ to increase biological diversity on the landscape may have similar benefits as those promoted in other Approaches (e.g., reduced runoff and erosion, improved soil health).[215] Unlike Strategy 4, Approach 3, which refers to diversity within agricultural systems, this Approach underscores some of the benefits of biological diversity on the land surrounding agricultural systems and highlights some on-farm practices that can help to increase diversity at the landscape level.

Examples of adaptation practices include:

- **Practice 6.2.1: Create and maintain pollinator habitat for wild bees** within agroecosystems, such as with hedgerows or wildflowers (also see Approach 3.1), or on-field cover crops (also see Approaches 1.1, 1.2, and 3.3).
- **Practice 6.2.2: Promote diverse non-crop vegetation types** that can support arthropod predators and insect-eating birds and bats[216] (also see Approach 3.1).

- **Practice 6.2.3: Maintain wildlife corridors** that can allow wildlife populations to travel across multiple properties, impeded by roads and other human activity as little as possible.[217]
- **Practice 6.2.4: Increase crop diversity in plantings when planting across multiple fields.** Diversifying crop types across a landscape may benefit the biological diversity of pollinators and birds as effectively as incorporating natural or semi-natural landcover.[218]

Approach 6.3: Conserve Individual Farms

California's farms play an important role in adapting to and mitigating some of the effects of climate change.[219] Perennial agriculture, tap-rooted cover crops, and minimally-disturbed soils can all serve to sequester carbon, and California's irrigated agricultural land emits far less greenhouse gases (GHGs) per acre than urban lands.[205] Farms can also provide additional services to the surrounding area, including limiting heat effects[220] and providing opportunities for water supply improvement that may benefit the broader community. Although the growing population and associated land use changes consumed more than 1 million acres of the state's agricultural lands between 1984 and 2014,[221] by conserving farms as working landscapes, California can benefit from their unique role in combating climate change. Some steps that may preserve California farmland viability are noted here.

Examples of adaptation practices include:

- **Practice 6.3.1: Encumber property with a conservation easement,** possibly with an affirmative farming covenant.
- **Practice 6.3.2: Participate in the Williamson Act.** Participation allows landowners to voluntarily conserve farmland by restricting land conversion away from agricultural use during a defined contract period. This stabilizes the landscape in the short term (10-20 years) and provides tax benefits for landowners.
- **Practice 6.3.3: Create a farm succession plan** to ensure that the land will remain agricultural or working. Organizations such as Farmlink can help facilitate this action.

Strategy 7: Develop or Expand Co-Benefit Efforts to Mitigate Climate Change

California is integral to the national food system. As such, it is notable that since the United States signed the UN Framework on Climate Change in 1992, annual GHG emissions in the U.S. have decreased by 7% (1990-2020),[222] while California's emissions have declined by 3% (1990-2019), and the California agricultural sector has performed similarly (down 3% in 2000-2019).[223] Many programs have been implemented to lower California agriculture's GHG footprint, with effects that can take years to become apparent, but there is still great potential for action.

Many climate adaptation practices have co-benefits, and those co-benefits can reach above the farm level. One such co-benefit is climate change mitigation, such as when carbon is sequestered in the soil or greenhouse gas emissions are reduced. Carbon dioxide (CO_2) and nitrous oxide (N_2O) are the principal greenhouse gases emitted by California specialty crop farm management practices. On-farm emissions and carbon sequestration can be measured in a variety of ways. For example, on-farm CO_2 emissions can be quantifiably reduced by improving the energy efficiency of farm equipment switching to electrical power, and/or sourcing electricity from utilities that are less dependent on fossil fuels. Carbon (C) sequestration can be quantified by widely-available soil analyses, measuring changes in organic carbon levels within the soil, although the challenges and timescale required should be understood ahead of time. Nitrous oxide emissions can be reduced by lowering nitrogen (N) fertilizer applications, or through changes in irrigation or fertigation, which have been studied extensively in California.[224] The approaches and examples of practices listed below may be useful in sequestering carbon and mitigating other GHG emissions.

Approach 7.1: Reduce On-Farm Greenhouse Gas Emissions

Carbon dioxide is not generally emitted in large quantities by soils that have been under long-term cultivation in California. However, equipment such as tractors and diesel pumps are responsible for on-farm CO_2 emissions and also make up a large part of California agriculture's GHG footprint.[225] Also, it is estimated that in California specialty crop production, on-farm nitrous oxide emissions contribute even more than CO_2 to total on-farm emissions.[223] Nitrous oxide is primarily emitted under conditions of excess nitrogen, high moisture, and adequate temperatures in the soil.[226] Management of nitrogen-bearing fertilizers is the key to reducing N_2O emissions. Fortunately, nitrogen management goals such as reducing cost, improving N productivity,[227] and improving soil health,[228] generally help to lower N_2O, so that the reduced emissions are a co-benefit.

Examples of mitigation practices include:

- **Practice 7.1.1: Pursue "incremental progress"** such as energy audits, variable frequency drives on electric pumps, upgrades of diesel equipment to engines with the best available emissions technology, etc.
- **Practice 7.1.2: Invest in electric-powered equipment** such as electric irrigation pumps or electric tractors (SWEEP, FARMER, and Carl Moyer funds may assist California growers).
- **Practice 7.1.3: Consider using rooftops and residual areas for solar or wind power generation.** Mixed crop-and-solar-panel "agrivoltaic" systems now being developed may optimize land use overall,[229] especially where water supplies are lower than demand.[155]
- **Practice 7.1.4: Reduce soil nitrous oxide emissions** through efficient and timely N management (e.g., fertigation,[224] controlled release N fertilizers,[230] and/or urease or nitrification inhibitors[231]).

Moving to electric farm equipment such as electric tractors is one way to reduce on-farm greenhouse gas emissions, thereby expanding on-farm efforts to mitigate climate change.

Approach 7.2: Increase On-Farm Soil Carbon Sequestration

Since 1970, atmospheric carbon has increased from 325 parts per million (ppm) to 412 ppm,[232] and that increase is the main driver of the climatic shifts discussed in earlier sections of this workbook. Research suggests that California farms can provide opportunities to capture carbon and store it in the soil as organic matter.[233,234] Because agricultural soils typically have 25-75% less organic carbon than their undisturbed counterparts,[235] carbon capture into cultivated soils provides "regenerative" soil health benefits (see also Strategy 1). Moreover, capturing carbon from the atmosphere into the soil supports all of the Strategies in this workbook, ultimately serving to increase resilience to climate change, input efficiency, and food security.[236]

On-farm soil carbon sequestration can occur in a number of ways. It is limited by soil type and climate as well as whether the land is irrigated, but will also depend on three principal management decisions. First is the quantity of

Reducing On-Farm Greenhouse Gas Emissions at Jackson Family Wines

Like any other industry, agricultural operations emit carbon dioxide into the atmosphere. Reducing on-farm greenhouse gas (GHG) emissions is one way to decrease an operation's carbon footprint. **Jackson Family Wines** is an excellent example of an operation that is actively reducing their GHG emissions by making **incremental changes**.

As a family-owned company, multigenerational sustainability is integral to the Jackson Family Wines mission. After seeing the effects of climate disasters on their operations, the company set a goal of **cutting their carbon footprint in half by 2030 and becoming climate positive by 2050** without purchasing carbon offsets.

Using their 2015 emissions as a baseline, Jackson Family Wines calculated that they need to reduce their carbon footprint by 4% each year in order to reach their goals. To achieve this, they are focusing on efforts such as **transitioning to electric vehicles, reinvesting renewable energy**, shifting to lighter weight glass wine bottles, and going "zero-waste."

Jackson Family Wines is pursuing these changes to act as a leader in their industry and show that companies can do a lot to be agents of change.

Read more about what Jackson Family Wines is doing to reduce their GHG emissions here!

organic amendments, including crop residues. Second is the quality of those amendments. Long-lasting, "resistant" soil organic matter is largely made up of deceased microorganisms, which have a carbon-to-nitrogen ratio of 10:1, so organic amendments ideally have a C:N ratio of 24:1 or lower (understanding that a good deal of carbon will be used for microbial energy, while most nitrogen will go into microbial or plant biomass). Some studies indicate that large additions of organic amendments above a 24:1 ratio will cause nitrogen hunger for the crop and will fail to produce resistant soil organic matter unless accompanied by a nitrogen supplement,[237,238,239] but the field results for soil carbon have been mixed. Thirdly, the conflict between reduced tillage systems with residue retention, and cover-cropping or amendment practices requiring more tillage, must be assessed for each case. Tillage causes losses of organic matter. With additional tillage, seasonal cover cropping will still improve soil health, but in Californian conditions it has often failed to measurably increase soil carbon.[28,32,233]

Examples of mitigation practices include:

- **Practice 7.2.1: Implement the Practices from Approaches 1.1 and 1.2.** The practices likely to produce the greatest soil carbon increases are the retention of residues and elimination of tillage. With organic amendments, the effects depend on type of amendment, amount, soil type, and tillage.
- **Practice 7.2.2: Plan ahead for soil carbon sampling, using established protocols.** CDFA's Healthy Soils Program includes recommendations for when, where, and how to prepare. See Resources for more information.
- **Practice 7.2.3: Consider using biochar for future use.** Biochar has soil benefits beyond carbon sequestration, but as a newer technology, various forms of biochar are still being studied, and how long it will remain in the soil and how durable its C sequestration benefits may be are still not known.[240]
- **Practice 7.2.4: Plant woody perennials or cover crops with taproots** for deeper soil C deposition with higher retention.[241,242] With perennials, carbon will also be stored in the plant for as long as it stands.
- **Practice 7.2.5: Monitor soil N and consider N supplementation for high-carbon organic amendments.** Both crop health and resistant soil carbon buildup are the aims of this Practice.

RESOURCES

Many web-based resources are linked above in this workbook. When using a print version of the workbook, the website addresses (URLs) below correspond to the sites linked in the text above. Should you wish to visit these websites, they are organized by workbook Section and are listed in the order in which they appear.

A Guide for Adaptation Planning

Resource Name	Resource Owner	Resource Type and Description	URL
Climate Risks to California Agriculture	USDA California Climate Hub	This **fact sheet** provides a 30,000-foot view of some climate risks affecting California Agriculture and explains some ways that the California Climate Hub can assist producers impacted by these changes.	https://www.climatehubs.usda.gov/sites/default/files/Climate%20Risks%20for%20Ag%20FS%20050220.pdf
California Crops Under Climate Change	USDA California Climate Hub	This **story map** provides a broad overview of California as "America's Fruit and Nut Basket", the challenges specialty crop production will face, and the potential climate adaptive opportunities that can support California agriculture.	https://www.climate-hubs.usda.gov/hubs/california/california-crops-under-climate-change
Resist-Accept-Direct (RAD) – A Framework for the 21st-century Natural Resource Manager	National Parks Service, U.S. Department of the Interior	This **white paper** breaks down the Resist-Accept-Direct (RAD) decision framework in the context of natural resource management, and explains how it can be used by natural resource managers collaborating at larger scales across jurisdictions.	https://irma.nps.gov/DataStore/DownloadFile/654543
R–R–T (resistance–resilience–transformation) typology reveals differential conservation approaches across ecosystems and time	Communications Biology	This **peer reviewed paper** explains the proposed 6-point continuous interval scale representing different stages of action (or in-action) from active resistance to accelerated transformation.	https://www.nature.com/articles/s42003-020-01556-2
Climate Change Response Framework and Adaptation Workbook	USDA Climate Hubs, USFS, American Forests, Northern Institute of Applied Climate Science	This **landing page** walks viewers through an explanation of what their Adaptation Workbook for Forests is, and provides a 'quick guide', training, and demonstrations.	https://forestadaptation.org/adapt/adaptation-workbook

Resources Mentioned in Step 1: Defining Goals and Objectives			
Resource Name	**Resource Owner**	**Resource Type and Description**	**URL**
Managing Salts by Leaching	University of California, Agriculture and Natural Resources	This **fact sheet** provides information on how growers can manage various types of crops impacted by salinity through leaching.	https://anrcatalog.ucanr.edu/pdf/8550.pdf

Resources Mentioned in Step 2: Assessing Climate Impacts and Vulnerabilities			
Resource Name	**Resource Owner**	**Resource Type and Description**	**URL**
California's Fourth Climate Change Assessment	California Governor's Office of Planning and Research	This **statewide climate report** provides information for building resilience to climate impacts throughout the state.	https://climateassessment.ca.gov/
Resilient California	California's Governor's Office of Planning and Research	This **clearinghouse site** includes several tools, data, scientific studies, and more to help Californians adapt to climate change.	https://resilientca.org/tools/
Vulnerability and Adaptation to Climate Change in California Agriculture	California Water Library, California Energy Commission, UC Davis	This **white paper/ vulnerability assessment** lays out California's agricultural vulnerability, taking into account 22 climate, crop, land use, and socioeconomic variables.	https://cawaterlibrary.net/document/vulnerability-and-adaptation-to-climate-change-in-california-agriculture/
CalAgroClimate	University of California Agriculture and Natural Resources and the USDA California Climate Hub	This **decision support tools** site hosts interactive web tools and related resources to help California farmers make on-farm management decisions.	https://calagroclimate.org/
Cal-Adapt	California Energy Commission, State of California	This **decision support tools** site includes interactive web tools for visualizing past and projected climate metrics across California.	https://cal-adapt.org/
The Climate Toolbox	University of California, Merced	This **clearinghouse site** includes a collection of tools and resources for visualizing past and projected climate and hydrology of the contiguous United States.	https://climatetoolbox.org/
U.S. Climate Resilience Toolkit	U.S. Global Change Research Program, U.S. National Oceanic and Atmospheric Administration	This **clearinghouse site** includes a collection of tools, case studies, and additional information and resources to improve resilience through improving understanding of climate-related risks and opportunities.	https://toolkit.climate.gov/
*Refer to the quick start guides and/or tutorials for the web tools above for more information on how they can be used to assess the climate conditions on your farm.			

Provided below are more resources that can aid in your adaptation planning, in addition to those linked in the document above. These resources are organized by the menu Strategy and Approach that they principally correspond to, although some resources can be used for multiple Strategies, Approaches, and Practices. For those referencing a print version of this workbook, complete web addresses are also provided should you wish to visit these websites.

STRATEGY 1: Support and Maintain Soil Health, Soil Biological Services, and Water Quality

Approach 1.1: Maintain and Improve Soil Structure			
Resource Name	**Resource Owner**	**Resource Type and Description**	**URL**
USDA NRCS Conservation Practice 340: Cover Crops	USDA NRCS	This **website** is part of a series of conservation practices highlighted by the USDA NRCS. It hosts resources that describe the definition, purpose, and environmental considerations land managers may consider when implementing cover crops.	https://www.nrcs.usda.gov/resources/guides-and-instructions/cover-crop-ac-340-conservation-practice-standard
USDA NRCS Conservation Practice 327: Conservation Cover	USDA NRCS	This **website** is part of a series of conservation practices highlighted by the USDA NRCS. It hosts resources that describe the definition, purpose, and environmental considerations land managers may consider when implementing conservation cover.	https://www.nrcs.usda.gov/resources/guides-and-instructions/conservation-cover-ac-327-conservation-practice-standard
USDA NRCS Plant Materials Technical Documents	USDA NRCS	This **clearinghouse page** provides various publications published by the Lockeford Plant Materials Center to help land managers implement conservation practices.	https://www.nrcs.usda.gov/plant-materials/publications/search

Approach 1.2: Enhance Soil Biology and Nutrient Availability with Organic Amendments			
Resource Name	**Resource Owner**	**Resource Type and Description**	**URL**
USDA NRCS Interim Conservation Practice 808: Soil Carbon Amendment. **NOTE:** When adopted as a permanent standard, expected in late 2022, this will become Practice 336.	USDA NRCS	This **fact sheet** is part of a series of conservation practices highlighted by the USDA NRCS. It describes the definition, purpose, and environmental considerations land managers may consider when adding soil carbon amendments.	https://efotg.sc.egov.usda.gov/api/CPS-File/10954/808_PI_ICPS_Soil_Carbon_Amendment_2020
NRDC Composting 101	Natural Resources Defense Council	This **web page** explains the basics of composting, from the various types to the do's and don'ts of the practice.	https://www.nrdc.org/stories/composting-101#howto
CDFA On-Farm Compost Resources	California Department of Food and Agriculture	This **web page** provides a series of resources for on-farm composting, including regulatory compliance, best practices, nutrient management creation, and more.	https://www.cdfa.ca.gov/healthysoils/ofcwg.html
UC Davis Grower's Guide to Whole Orchard Recycling	UC Davis	This **web page** provides FAQs, cost considerations, information on incentives, and lists of the multiple benefits related to Whole Orchard Recycling (WOR).	https://orchardrecycling.ucdavis.edu/growers-guide-wor

Approach 1.3: Manage for Soil and Water Salinization			
Resource Name	**Resource Owner**	**Resource Type and Description**	**URL**
USDA NRCS Conservation Practice 610: Saline and Sodic Soil Management	USDA NRCS	This **website** is part of a series of conservation practices highlighted by the USDA NRCS. It hosts resources that describe the definition, purpose, and environmental considerations land managers may consider when managing for salts and sodium in soil.	https://www.nrcs.usda.gov/resources/guides-and-instructions/saline-and-sodic-soil-management-ac-610-conservation-practice
Salinity Management Practices	UC ANR	This **web page** provides a host of information on the benefits of proper salinity management practices and how to implement them.	https://ucanr.edu/sites/Salinity/Salinity_Management/Salinity_management_practices/

Approach 1.4: Manage Fertilizer Application to Protect Groundwater Quality and Soil Health			
Resource Name	**Resource Owner**	**Resource Type and Description**	**URL**
NRCS Conservation Practice 590: Nutrient Management	USDA NRCS	This **website** is part of a series of conservation practices highlighted by the USDA NRCS. It hosts resources that describe the definition, purpose, and environmental considerations land managers may consider when implementing nutrient management practices.	https://www.nrcs.usda.gov/resources/guides-and-instructions/nutrient-management-ac-590-conservation-practice-standard

STRATEGY 2: Cope with Uncertain Water Availability

Approach 2.1: Improve or Alter Water Systems to Meet Current and Expected Future Demands			
Resource Name	**Resource Owner**	**Resource Type and Description**	**URL**
USDA NRCS Conservation Practice 441: Irrigation System, Microirrigation	USDA NRCS	This **fact sheet PDF** is part of a series of conservation practices highlighted by the USDA NRCS. It explains the definition, purpose, and ideal conditions for implementing microirrigation systems.	https://www.nrcs.usda.gov/sites/default/files/2022-11/IRRIGATION.pdf
USDA NRCS Conservation Practice 442: Sprinkler System	USDA NRCS	This **fact sheet PDF** is part of a series of conservation practices highlighted by the USDA NRCS. It explains the definition, purpose, and ideal conditions for implementing sprinkler systems.	https://www.nrcs.usda.gov/wps/PA_NRCSConsumption/download?cid=nrcseprd1822439&ext=pdf
USDA NRCS Conservation Practice 449: Irrigation Water Management	USDA NRCS	This **fact sheet PDF** is part of a series of conservation practices highlighted by the USDA NRCS. It explains the definition, purpose, and ideal conditions for implementing irrigation water management practices.	https://www.nrcs.usda.gov/sites/default/files/2022-10/FY23_DIA%20163_Irrigation%20Water%20Management%20Design.pdf

Approach 2.2: Manage for the Effects of Drought			
Resource Name	**Resource Owner**	**Resource Type and Description**	**URL**
USDA NRCS Conservation Practice 340: Cover Crops	USDA NRCS	This **website** is part of a series of conservation practices highlighted by the USDA NRCS. It hosts resources that describe the definition, purpose, and environmental considerations land managers may consider when implementing cover crops.	https://www.nrcs.usda.gov/resources/guides-and-instructions/cover-crop-ac-340-conservation-practice-standard
Deficit Irrigation Practices	Food and Agriculture Organization (FAO)	This is a **compilation of scholarly research** presented by the Food and Agriculture Organization in 2002, aiming to provide information on the ways crops react to drought stress	http://large.stanford.edu/courses/2016/ph241/lsm2/docs/wr22e.pdf
Drought Resistant Crops and Varieties List	UC ANR	This is a substantial, but not exhaustive, **list of crops and varieties** that can be drought tolerant or drought resistant.	https://ucanr.edu/sites/scmg/files/183771.pdf

Approach 2.3: Prepare for Changing Patterns of Precipitation			
Resource Name	**Resource Owner**	**Resource Type and Description**	**URL**
USDA NRCS Conservation Practice 412: Grassed Waterway	USDA NRCS	This **website** is part of a series of conservation practices highlighted by the USDA NRCS. It hosts resources that describe the definition, purpose, and ideal conditions for adding grassed waterways to a managed landscape.	https://www.nrcs.usda.gov/resources/guides-and-instructions/grassed-waterway-ac-412-conservation-practice-standard
USDA NRCS Conservation Practice 447: Irrigation and Drainage Tailwater Recovery	USDA NRCS	This **website** is part of a series of conservation practices highlighted by the USDA NRCS. It hosts resources that explain the definition, purpose, and ideal conditions for implementing irrigation and drainage tailwater recovery.	https://www.nrcs.usda.gov/resources/guides-and-instructions/irrigation-and-drainage-tailwater-recovery-no-447-conservation
USDA NRCS Interim Conservation Practice 817: On-Farm Recharge	USDA NRCS	This **website** is part of a series of conservation practices highlighted by the USDA NRCS. It hosts resources that describe the definition, purpose, and ideal conditions for implementing on-farm recharge.	https://efotg.sc.egov.usda.gov/api/CPSFile/30313/817_CA_ICPS_On_Farm_Recharge_2020

STRATEGY 3: Manage Biological Stressors

Approach 3.1: Reduce Pest Pressure			
Resource Name	**Resource Owner**	**Resource Type and Description**	**URL**
USDA NRCS Conservation Practice 595: Pest Management Conservation Systems	USDA NRCS	This **website** is part of a series of conservation practices highlighted by the USDA NRCS. It hosts resources that describe the definition, purpose, and ideal conditions for implementing pest management conservation systems.	https://www.nrcs.usda.gov/resources/guides-and-instructions/pest-management-conservation-system-ac-595-conservation-practice
USDA NRCS Conservation Practice 420: Wildlife Habitat Planning	USDA NRCS	This **website** is part of a series of conservation practices highlighted by the USDA NRCS. It explains the definition, purpose, and ideal conditions for establishing wildlife habitat by planting herbaceous vegetation or shrubs.	https://www.nrcs.usda.gov/resources/guides-and-instructions/wildlife-habitat-planting-ac-420-conservation-practice-standard
USDA NRCS Conservation Practice 645: Upland Wildlife Habitat Management	USDA NRCS	This **fact sheet PDF** is part of a series of conservation practices highlighted by the USDA NRCS. It explains the definition, purpose, and ideal conditions for providing and managing upland habitats and connectivity within the landscape for wildlife.	https://efotg.sc.egov.usda.gov/api/CPSFile/1281/645_MN_CPS_Upland_Wildlife_Habitat_Management_2016
USDA NRCS Conservation Practice 422: Hedgerow Planting	USDA NRCS	This **website** is part of a series of conservation practices highlighted by the USDA NRCS. It explains the definition, purpose, and ideal conditions for implementing hedgerows into one's landscape.	https://www.nrcs.usda.gov/resources/guides-and-instructions/hedgerow-planting-ft-422-conservation-practice-standard

Approach 3.3: Reduce Weed and Invasive Plant Pressure			
Resource Name	**Resource Owner**	**Resource Type and Description**	**URL**
USDA NRCS Conservation Practice 328: Conservation Crop Rotation	USDA NRCS	This **website** is part of a series of conservation practices highlighted by the USDA NRCS. It explains the definition, purpose, and ideal conditions for implementing conservation crop rotation onto one's landscape.	https://www.nrcs.usda.gov/resources/guides-and-instructions/conservation-crop-rotation-ac-328-conservation-practice-standard
USDA NRCS Conservation Practice 315: Herbaceous Weed Treatment	USDA NRCS	This **fact sheet PDF** is part of a series of conservation practices highlighted by the USDA NRCS. It explains the definition, purpose, and ideal conditions for removing or controlling herbaceous weeds, including invasive, noxious, prohibited, or undesirable plants from one's landscape.	https://www.nrcs.usda.gov/sites/default/files/2022-10/CO%20Herbaceous%20weed%20treatment%20E315A.pdf
UC ANR Integrated Pest Management Guidelines	UC ANR	This **webpage** details information about managing pests, broken down by crop type and then specific crop varieties. Information includes the University of California's official guidelines for monitoring pests and using pesticides and non-pesticide alternatives for managing insect, mite, nematode, weed, and disease pests.	https://www2.ipm.ucanr.edu/agriculture/

STRATEGY 4: Prepare for Temperature Change

Approach 4.1: Adapt to Warmer Conditions			
Resource Name	**Resource Owner**	**Resource Type and Description**	**URL**
USDA NRCS Conservation Practice 340: Cover Crops	USDA NRCS	This **website** is part of a series of conservation practices highlighted by the USDA NRCS. It describes the definition, purpose, and environmental considerations land managers may consider when implementing cover crops.	https://www.nrcs.usda.gov/resources/guides-and-instructions/cover-crop-ac-340-conservation-practice-standard
Chill Calculator	UC Davis Fruit & Nut Information Center	This **virtual chill calculator tool** shows both historic and projected chill hours per year at specific CIMIS Stations.	https://fruitsandnuts.ucdavis.edu/chill-calculator

Approach 4.2: Manage for Changing Seasonality			
Resource Name	**Resource Owner**	**Resource Type and Description**	**URL**
Map of Projected Change	CalAdapt	This **interactive webtool** shows maps of projected changes in long term (30 years) annual averages of maximum temperature, minimum temperature, and precipitation in California.	https://cal-adapt.org/tools/maps-of-projected-change

Approach 4.3: Prepare for Longer-Term and Larger-Scale Temperature Changes			
Resource Name	**Resource Owner**	**Resource Type and Description**	**URL**
Guidelines for Intercropping	Sustainable Agriculture Research and Education (SARE)	This **planning manual** can be used as a guide or reference for growers integrating crop rotations on their fields.	https://www.sare.org/publications/crop-rotation-on-organic-farms/guidelines-for-intercropping/ (introduction to the manual) https://www.sare.org/wp-content/uploads/Crop-Rotation-on-Organic-Farms.pdf (manual)

STRATEGY 5: Enhance Preparedness for Extreme Events

Approach 5.1: Prepare for Extreme Heat Events			
Resource Name	**Resource Owner**	**Resource Type and Description**	**URL**
Irrigation Scheduling Tables	Washington State University	This **webpage** includes Excel templates that allow users to schedule irrigation based on crop water use and soil moisture monitoring.	http://irrigation.wsu.edu/Content/Resources/Irrigation-Schedule-Tables.php

Approach 5.2: Manage for Extreme Precipitation and Flooding			
Resource Name	**Resource Owner**	**Resource Type and Description**	**URL**
USDA NRCS Conservation Practice 340: Cover Crops	USDA NRCS	This **website** is part of a series of conservation practices highlighted by the USDA NRCS. It describes the definition, purpose, and environmental considerations land managers may consider when implementing cover crops.	https://www.nrcs.usda.gov/resources/guides-and-instructions/cover-crop-ac-340-conservation-practice-standard
Flood Managed Aquifer Recharge Information Page	California Department of Water Resources (CDWR)	This government **webpage** explains what Flood-Managed-Aquifer Recharge is and its benefits, and provides additional outside resources for implementing the practice.	https://water.ca.gov/programs/all-programs/flood-mar

Approach 5.3: Enhance Resilience to Extreme Wind			
Resource Name	**Resource Owner**	**Resource Type and Description**	**URL**
USDA NRCS Conservation Practice 589: Cross Wind Trap Strips	USDA NRCS	This **website** is part of a series of conservation practices highlighted by the USDA NRCS. It describes the definition, purpose, and environmental considerations land managers may consider when incorporating cross wind trap strips.	https://www.nrcs.usda.gov/resources/guides-and-instructions/cross-wind-trap-strips-ac-589c-conservation-practice-standard
USDA NRCS Conservation Practice 380: Windbreak Shelterbelt Establishment	USDA NRCS	This **website** is part of a series of conservation practices highlighted by the USDA NRCS. It describes the definition, purpose, and environmental considerations land managers may consider when establishing, enhancing, or renovating windbreaks (aka, shelterbelts).	https://www.nrcs.usda.gov/resources/guides-and-instructions/windbreakshelterbelt-establishment-ft-380-conservation-practice

Approach 5.4: Prepare for and Respond to Wildland Fire and Smoke Impacts			
Resource Name	**Resource Owner**	**Resource Type and Description**	**URL**
USDA NRCS Conservation Practice 394: Firebreaks	USDA NRCS	This **website** is part of a series of conservation practices highlighted by the USDA NRCS. It describes the definition, purpose, and environmental considerations land managers may consider when integrating firebreaks into their landscape.	https://www.nrcs.usda.gov/resources/guides-and-instructions/firebreak-ft-394-conservation-practice-standard
USDA NRCS Conservation Practice 383: Fuel Breaks	USDA NRCS	This **website** is part of a series of conservation practices highlighted by the USDA NRCS. It describes the definition, purpose, and environmental considerations land managers may consider when adding fuel breaks into their landscape.	https://www.nrcs.usda.gov/resources/guides-and-instructions/fuel-break-ac-383-conservation-practice-standard

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