United States Department of Agriculture

ADAPTATION RESOURCES FOR AGRICULTURE

Responding to Climate Variability and Change in the Midwest and Northeast

A product of the USDA Midwest, Northeast, and Northern Forests Climate Hubs

Adaptation Resources for Agriculture:

Responding to Climate Variability and Change in the Midwest and Northeast

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U.S. Department of Agriculture
Washington, DC
Technical Bulletin 1944
October 2016

Published in cooperation with the USDA:
Midwest, Northeast, and Northern Forests Climate Hubs
Agricultural Research Service
Natural Resources Conservation Service
Forest Service

Abstract

Janowiak, M., D. Dostie, M. Wilson, M. Kucera, R. Howard Skinner, J. Hatfield, D. Hollinger, and C. Swanston. 2016. Adaptation Resources for Agriculture: Responding to Climate Variability and Change in the Midwest and Northeast. Technical Bulletin 1944. Washington, DC: U.S. Department of Agriculture.

Changes in climate and extreme weather are already increasing challenges for agriculture nationally and globally, and many of these impacts will continue into the future. This technical bulletin contains information and resources designed to help agricultural producers, service providers, and educators in the Midwest and Northeast regions of the United States integrate climate change considerations and action-oriented decisions into existing farm and conservation plans. An Adaptation Workbook provides producers a flexible, structured process to identify and assess climate change impacts, challenges, opportunities, and farm-level adaptation tactics and continuously evaluate adaptation actions for improving responses to extreme and uncertain conditions. A synthesis of Adaptation Strategies and Approaches serves as a “menu” of potential responses organized to provide a clear rationale for making decisions by connecting planned actions to broad adaptation concepts. Responses address both short- and long-range timeframes and extend from incremental adjustments of existing practices to major alterations that transform the entire farm operation. Example adaptation tactics—prescriptive actions for agricultural production systems common in the region—for each approach guide producers, service providers, and educators to develop appropriate responses for their farms and location. Four Adaptation Examples demonstrate how these adaptation process resources are used.

Keywords: climate change, adaptation, agriculture, adaptive management, Midwest, Northeast

Contents

Introduction

This publication provides perspectives, information, resources, and tools to producers, service providers, and educators in the Midwest and Northeast regions of the United States for responding to climate variability and change. Broadly defined, climate change adaptation includes all adjustments, both planned and unplanned, in natural and human systems occurring in response to climatic changes and subsequent effects (Parry et al. 2007; Smit et al. 1999). Since the effects of climate change are complex and far-reaching, and the scope, severity, and pace of future impacts are difficult to predict, numerous government agencies, universities, and private partners are working together to develop information, resources, and tools that support adaptation across all sectors of society. Of particular interest to agricultural producers and other land managers, the USDA is providing coordinated climate change assistance through the Regional Climate Hubs. The USDA Climate Hubs develop and deliver science-based, region-specific information and tools to land managers to enable climate informed decision making and provide access to USDA resources to implement those decisions.

In this publication, we focus on the deliberate integration of climate change information into short-term management (< 5 years) and long-range planning (5 to 20 or more years), decisionmaking, and implementation actions within the control of agricultural producers (Box I.1). As newer, more precise information becomes available to improve decisionmaking, farmers should consider modifying long-range plans. While it is beyond the scope of this publication to comprehensively address all potential adaptations within the agricultural system, such as new technologies or changes in tariffs or the use of crop insurance programs, it is possible to extend the use of scientific information about future climate change impacts to the scale of individual farms. Individual farms have unique goals in the areas of profitability, productivity, land stewardship, or any combination thereof, depending on unique needs, and many climate change adaptation actions can benefit these farm-wide goals while also adjusting systems to changing conditions.

The contents are organized as a set of interrelated chapters, each of which serves as an independent resource to help incorporate climate considerations into on-farm agricultural practices and develop adaptation actions that can be used to respond to climate variability and change.

- ***Chapter 1: Climate Change Effects on Agriculture and Natural Resources*** briefly summarizes the effects of climate change on agriculture and natural resources of the Midwest and Northeast regions of the United States.
- ***Chapter 2: Adaptation in Agriculture*** describes the role adaptation plays to help agricultural producers respond to the challenges and opportunities associated with climate variability and change.
- ***Chapter 3: Adaptation Strategies and Approaches*** provides a synthesis of on-the-ground (i.e., farm- and landscape-level) climate adaptation strategies and approaches as a "menu" of potential responses.
- ***Chapter 4: Adaptation Workbook*** presents a structured process for integrating climate change considerations and action-oriented decisions into the farm's long range and annual operation plans.
- ***Chapter 5: Adaptation Workbook Examples*** demonstrates how to use the **Adaptation Workbook** together with regional **Adaptation Strategies and Approaches** to develop tactics for real-world farm operations within the Midwest and Northeast regions of the United States.

Box I.1: About the Adaptation Resources for Agriculture

The Adaptation Resources for Agriculture:

- Supports producers, service providers, and educators in the Midwest and Northeast Regions of the United States.
  - **Midwest:** Michigan, Ohio, Indiana, Illinois, Missouri, Kansas, Nebraska, South Dakota, North Dakota, Minnesota, Wisconsin, and Iowa.
  - **Northeast:** Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Maryland, Delaware, West Virginia and the District of Columbia.
- Helps producers consider both short-term adaptive management actions (< 5 years) and long-range strategic plans (5 to ~20 years, subject to farm type)
- Promotes adaptation through multiple resources, including:
  - A "menu" of many adaptation strategies and approaches (Chapter 3) and example tactics for row cropping and forages, confined livestock, grazing, orchards, and small fruit and vegetable production systems.
  - A five-step process outlined in the Adaptation Workbook (Chapter 4) to help producers incorporate climate change considerations into existing plans and develop adaptation actions at the scale of farms and fields .
  - Examples where climate change has been considered in real-world agricultural situations using the Resources provided by this publication (Chapter 5).

The Resources in This Publication Do Not:

- Recommend specific management actions or policy.
- Address the non-climate-related risks of an agricultural enterprise, such as production, marketing, financial, human resource, and legal factors.
- Attempt to list all possible climate adaptation actions that a producer might implement.

Leaves harness sunlight to convert atmospheric carbon dioxide into life-sustaining food and energy.

CHAPTER 1:
Climate Change Effects on Agriculture and Natural Resources

Changes in climate and extreme weather have already occurred and are increasing challenges for agriculture nationally and globally. Many of the impacts are expected to continue or intensify in the future. The effects of a changing climate and enhanced climate variability are already being seen across the Midwestern and Northeastern United States; over the past century, temperatures have risen across all seasons, growing seasons have become longer, precipitation patterns have changed, and extreme precipitation events have increased in frequency and severity (Hatfield et al. 2015; Hatfield et al. 2014; Tobin et al. 2015). Because of the sensitivity of agriculture to weather and climate conditions, these impacts can have substantial direct and indirect effects on farm production and profitability.

Ongoing changes in climate have substantial impacts on the $98 billion agricultural sector in the Midwest and Northeast (Hatfield et al. 2015; Tobin et al. 2015). Diversity across these two regions, both in terms of climate and in agricultural commodities produced, indicates that potential responses to climate change will vary by location and commodity (Hatfield et al. 2015; Tobin et al. 2015; Gordon et al. 2015). In the south of this region, agricultural commodities are expected to be more vulnerable where the full effects of warmer temperatures and associated changes will be strongest (Gordon et al. 2015), while

> "Climate change poses unprecedented challenges to U.S. agriculture because of the sensitivity of agricultural productivity and costs to changing climate conditions."
>
> Source: Climate Change and Agriculture in the United States: Effects and Adaptation. (Walthall et al. 2012)

extreme rainfall events are expected to be more common to the north and east (Kunkel et al. 2013). One analysis in the Midwest projected that major commodity crops, including corn, soybeans, and wheat, will be increasingly susceptible to lower crop yields without significant adaptation (Gordon et al. 2015).

Although some regions and sectors may have improved yields, the overall impacts of climate change are generally expected to be negative (Ainsworth and Ort 2010; Hatfield et al. 2014). Individual producers may experience increased risks from heat stress on crops and livestock, damage to commodities and infrastructure from extreme events, and long-term challenges as current systems, practices, crops, and breeds become increasingly less suited to climatic conditions. Ecosystem services may also be altered or disrupted (Box 1.1). As changes in the mean climate and climate variability become more pronounced, it will

Box 1.1: Effects on Ecosystem Goods and Services

Agriculture is an essential activity that supports human life. While agriculture supplies the food, fibers, and other materials used in everyday life, it also provides a much wider array of ecosystem services and goods that support human well-being. These ecosystem services are numerous and complex (Ahmed 2002), and it is not possible to assess all of the ways in which they are potentially affected by changes in weather and climate (Walthall et al. 2012). For these reasons the effects of climate change on agriculture must always be considered within the context of other changes happening within natural and socioeconomic systems.

Ecosystem services provided by agroecosystems include:

- **Provisioning services,** which provide food, pharmaceuticals, fiber, and fuel products.
- **Regulating services,** which regulate ecosystem processes such as groundwater flow; erosion control; flood protection; water purification and temperature control; pollination, weed, insect, disease, and parasite pest control; air quality and greenhouse gas emission control; carbon sequestration; local climate modification; and biodiversity.
- **Cultural Services,** which provide non-material benefits such as spiritual enhancement, tourism and recreational opportunities, and aesthetic experiences.
- **Supporting Services** that include basic soil aggregate arrangement, hydrological cycling, atmospheric and mineral nutrient cycling, and wildlife habitat.

become increasingly important to address potential risks to agricultural production and food security (Howden et al. 2007; Walthall et al. 2012).

Climate Change and Agriculture in the Midwest and Northeast

Numerous assessments describe both the observed and anticipated global, national, and regional changes in climate and associated effects on agriculture (Box 1.2). This section summarizes some of the most important changes that have already occurred and their effects relevant to the crop and livestock production systems typically found in the Midwest and Northeast regions of the United States. Changes in temperature, precipitation, concentration of carbon dioxide in the atmosphere, and other climatic factors directly affect production either positively or negatively, while severe weather and other climate-related hazards increase the risk of damage and adverse economic impacts. Already the number of weather- or climate-related disasters costing more than 1 billion dollars is increasing (Smith and Katz 2013, Walthall et al. 2012). Shifts in weeds, insects, or disease infestation, and their range, frequency, and intensity may in turn indirectly affect agriculture and amplify or counteract the direct effects of climate change. As these changes continue to intensify into the future, they may add new stress, exacerbate existing stressors in agroecosystems, or result in new opportunities for agriculture production.

Direct Effects of Changing Climate Conditions on Crops and Livestock

- **Annual average and seasonal air temperatures are increasing.** Average annual air temperatures have increased by 1 to 4 °F (2 °C) over the past century (Kunkel et al. 2013b; Kunkel et al. 2013a). The greatest warming has occurred along coastal margins and in the north, including the upper Great Lakes, and during the winter season. Temperatures are projected to increase another 4.5 to 9.5 °F by 2085. Changes in expected average annual temperatures greatly affect the selection of perennial crop species and varieties, livestock species and breeds, and engineering design criteria for livestock building construction, and energy supply.
- **Seasons are shifting.** The length of the frost-free season has increased by 9 to 10 days across the Midwest and Northeast, and it is expected to increase by 18 to 30 days by 2055 (Kunkel et al. 2013b; Kunkel et al. 2013a). Earlier spring thaws and later first frosts in autumn could result in greater growth and productivity, but only if temperatures do not exceed upper limits for growth, there is enough water and nutrients, and disease and pathogens are not constraints (Fuhrer 2003). However, earlier spring thaws can be detrimental to fruit production if early bud development increases exposure to late spring frosts. Growing degree-days for crops are shifting, creating opportunities to experiment with new crops, varieties, and markets. Heating or cooling degree-days for livestock and energy use are similarly shifting.

Water runoff from a heavy rain negatively impacts crop production and downstream water bodies.

- **The number of hot days and hot nights are increasing.** Nighttime temperatures have persistently increased during the 20th century, and this trend is expected to continue (Kunkel et al. 2013a; Kunkel et al. 2013b). Extreme high temperatures (defined as greater than 90^{o} F) and heat waves are also projected to increase (Walsh et al. 2014). Without a cooling off period at night, animals become more subject to heat stress, especially when coupled with higher relative humidity. Warmer summers may shorten the period for small grain to mature, and high nighttime temperatures can adversely affect plant biomass accumulation, crop yields, and quality.
- **Precipitation patterns are changing.** Annual precipitation has increased in the Midwest and Northeast, and there has been a shift toward larger precipitation events (Kunkel et al. 2013a; Kunkel et al. 2013b). Future precipitation amounts have a high degree of uncertainty, but point toward the potential for increased cold-season precipitation and relatively less change in precipitation during the growing season. More intense and concentrated precipitation events are expected to create wetter soils under these conditions, while at the same time, increased temperatures and evapotranspiration may lead to drier soil conditions between precipitation events (Bryan et al. 2015; Hatfield et al. 2014). This could lead to increased frequency of soil moisture stress or drought and suppressed crop yields.
- **Higher concentrations of atmospheric carbon dioxide may disproportionately benefit plant species.** More than 95 percent of the world's plant species assimilate carbon dioxide from the atmosphere using the C_3 pathway, while the rest use the C_4 pathway. The most recognizable crop species in the C_4 category include sugarcane and corn. Under elevated carbon dioxide concentrations, C_3 plants are often better able to increase production in response to additional carbon dioxide than C_4 plants (Walthall et al. 2012). Many confounding factors in the environment, such as interactions with tropospheric ozone pollution, influence plant response to changing climate.

Box 1.2: Climate Change Assessments

Climate change assessments are important resources that summarize and detail climate impacts across various sectors, regions, and ecosystems. Through the multitude of reports, it is clear that the climate is already changing with visible consequences at State, regional, national, and international levels.

- Walthall, C.L., et al. 2012. Climate Change and Agriculture in the United States: Effects and Adaptation. United States Department of Agriculture. 186 p. Available at www.usda.gov/oce/climate_change/effects.htm.
- Melillo, J.M., T.C. Richmond, G.W. Yohe, (eds.). 2014. Climate Change Impacts in the United States: the Third National Climate Assessment. U.S. Global Change Research Program. 841 p. Available at www.nca2014.globalchange.gov/downloads.
- Tobin, D., M. Janowiak, D. Hollinger, R.H. Skinner, C. Swanston, R. Steele, R. Radhakrishna, A. Chatrchyan. 2015. Northeast Regional Climate Hub Assessment of Climate Change Vulnerability and Adaptation and Mitigation Strategies. United States Department of Agriculture. 65 p. Available from the USDA Northeast Climate Hub at www.climatehubs.oce.usda.gov/northeast.
- Hatfield, J., C. Swanston, M. Janowiak, R. Steele, J. Hempel, J. Bochicchio, W. Hall, M. Cole, S. Hestvik, J. Whitaker. 2015. Midwest and Northern Forests Regional Climate Hub Assessment of Climate Change Vulnerability and Adaptation and Mitigation Strategies. United States Department of Agriculture. 55 p. Available from the USDA Midwest Climate Hub at www.climatehubs.oce.usda.gov/midwest.

Hazardous Risks to Agriculture From Weather and Climate

- **An increase of extreme precipitation events increases risk of damage to crops, soils, and infrastructure.** In the Northeast, the region has experienced a greater than 70 percent increase in extreme precipitation since the mid-1900s (Walsh et al. 2014). Intense rainfall events and excessive rain caused by multiple events passing over the same area in a short period of time can erode soils; damage crops and infrastructure; overtop waste storage facilities; delay planting or harvesting; transport sediment, nutrients, and pesticides offsite; and result in greater expenses and/or lower yields.
- **An increase of flood damage is also expected.** Areas of the Northeast and Midwest are vulnerable to increased flooding due to changes in the frequency or intensity of extreme precipitation events including thunderstorms, tropical storms, and coastal storm surges (Melillo et al. 2014). Often flood damage occurs well downstream of the area receiving the extreme precipitation, a greater concern in the Midwest due to the extent of agricultural lands located in flood-prone areas. Flooding may also cause more erosion along flashy streams in steep mountainous areas and in coastal areas of the Northeast subject to storm surges. Floods may render crops unsuitable for market, delay planting, and damage young plants. They may also increase risks of soil compaction from using heavy equipment on wet soils; transport of sediment, nutrients, and pesticides; and contamination of agricultural fields with pollutants carried from upstream sources.
- **Severe wind and storm hazards may increase.** Thunderstorms, tornadoes, hail, lightning, strong winds, severe snow, and ice storms currently occur in the Midwest and Northeast, and it is unclear whether these events will become more common in the future. Severe storms cause human and livestock fatalities and injuries and damage to crops and infrastructure. The Northeast has already experienced an increase in severe tropical storms and hurricanes compared to other regions and can expect the risk of hazards from them to continue increasing.
- **Warmer temperatures increase the potential for soil moisture stress and drought.** Higher temperatures drive water losses from evaporation and plant transpiration. A large amount of agriculture in the Midwest and Northeast is not irrigated, increasing vulnerability of these crops to summer drought and associated economic impacts (Hatfield et al. 2015; Tobin et al. 2015). Droughts may cause declines in crop yield and quality and shortage of forage supply on pasture. In addition to agricultural impacts, droughts affect water supplies, resulting in potential water use restrictions in metropolitan areas and may result in competition of limited water resources by urban and agricultural users.

Indirect Effects of Climate Change on Agriculture

- **Competition from weeds and invasive plant species may increase.** The complexity of the system and how direct and indirect effects of climate change influence plants makes projecting net outcomes challenging. Complex interactions between elevated carbon dioxide, higher temperatures, and altered precipitation may influence the success of weedy and invasive plant species within plant communities (Walthall et al. 2012). Extreme climatic events, such as drought, flooding, and strong storms, which are predicted to become more frequent with climate change, may also be a factor.
- **Populations of many damaging insects may increase.** Insects that overwinter in the Northeast, such as corn earworm, flea beetle, and the spotted-wing Drosophila, are already present at higher levels earlier in the season and this trend is expected to continue as temperatures warm (Tobin et al. 2015). Shorter winters bring an earlier arrival of migratory insects, allowing more generations of pests to develop within a season (Walthall et al. 2012).
- **The risk of plant pathogens may rise.** Increased temperature can increase pathogen survival over winter, can increase the period of infectivity, allow for more infection cycles in season, and result in pathogen populations expanding into new areas (Elad and Pertot 2014).
- **The risk of pressure from pathogens and parasites of livestock may rise.** Earlier springs and warmer winters may allow for greater proliferation and survivability of animal pathogens, parasites, and disease vectors. Hotter weather has the potential to increase the incidence of several health issues affecting dairy cows or increase the potential of toxin-producing fungi in forage (Gaughan et al. 2009).

CHAPTER 2:
Adaptation in Agriculture

As the scientific understanding of the effects and consequences of climate variability and change improves, agricultural producers are searching for ways to apply this information to planning and decisionmaking and put it into action. Broad descriptions of climate change effects are widely published in scientific literature, but each farm will be uniquely impacted and require customized responses (Box 2.1). This chapter describes the role of adaptation in agriculture in responding to the challenges and opportunities associated with climate variability and change and provides context for the **Adaptation Strategies and Approaches** presented in the next chapter. Often these responses can simultaneously provide co-benefits towards multiple goals, such as soil health improvement, water quality protection, wildlife habitat management, or greenhouse gas mitigation (Box 2.2), and may or may not be distinguishable from on-farm practices already planned or underway.

What is climate change adaptation?

Climate change adaptation can help to reduce the risks from climate variability and change, increase the resilience of systems to potential disruptions, and even alter systems to be better able to take advantage of future conditions. Climate adaptation includes all adjustments, both planned and unplanned, in natural and human systems occurring in response to climatic changes and subsequent effects (Smit et al. 1999; Parry et al. 2007). Adaptation actions are generally intended to address the greatest risks brought about by climate variability and change, but they can also spur innovative solutions and opportunities (Walthall et al. 2012).

It is important to acknowledge that agricultural producers continuously adjust to changing conditions. These may include market price fluctuations, increasing input costs, new neighbors, labor shortages, pest invasions, and adverse weather conditions. These adjustments to farm operations are critical to maintaining production, profit, and stewardship levels. At the same time, producers may need to make additional adjustments to respond to a wider potential for extreme weather events, increased variations in climate, and changes in long-term climate trends.

Box 2.1: Principles of Adaptation

Agricultural producers have many tools available to begin addressing climate change; however, a new perspective is needed to expand management considerations to new issues, spatial scales, timing, and prioritization of efforts. The following principles can serve as a starting point for this perspective (Swanston and Janowiak 2012):

- **Prioritization and triage:** Prioritize actions for adaptation on resources that are vulnerable and the likelihood that actions to reduce vulnerability will be effective.
- **Flexible and adaptive management:** Maintain a decisionmaking framework that is flexible and incorporates new knowledge and experience over time, in this case with impacts from climate variability and change.
- **"No regrets" decisions:** Look for actions that result in a wide variety of benefits under multiple scenarios and have little or no risk.
- **Precautionary actions:** Where vulnerability is high, taking precautionary actions to reduce risk in the near term is extremely important.
- **Support mitigation:** Many adaptation actions are complementary with actions to mitigate greenhouse gas emissions. Practices that help adapt farms to changing conditions may also reduce emissions or sequester carbon (Box 2.2).

Applying Adaptation Concepts to Agriculture

Greater climate variability and change increases the need for producers to be able to cope with changing, uncertain, and increasingly novel situations. Within the agriculture sector, adaptation can occur at a variety of scales ranging from sector-wide changes, (e.g., trade policies, government programs, insurance options, and technologies) to site-specific responses, (e.g., production system inputs, tillage, crop species, crop rotations, and harvest strategies) (Walthall et al. 2012; Hatfield et al. 2014; Smit and Skinner 2002). Further, adaptation strategies for agriculture can be divided into broad categories: farm production practices, farm financial management, farm infrastructure, new technological developments, and government programs and insurance. The first three categories involve enterprise-scale decisionmaking by producers while the last two address the broad socioeconomic system and are typically the responsibility of public agencies and agribusiness (Walthall et al. 2012; Smit and Skinner 2002).

This document provides information to work on the scale of farms and fields where an agricultural producer has control for decisionmaking and action. First steps are likely to focus on incorporating climate considerations into existing decisionmaking and planning activities, changing management as appropriate to respond to new challenges and opportunities, and increasing capacity to cope with more change in the future. It's important to recognize that the scales used to present climate change information (e.g., for regions or States, or for the middle or end of the century) are not the same as those used to make farm-level decisions (e.g., for farms or fields, or for the next season, year, or decade (Schmidt et al. 2014; Howden et al. 2007). For this reason, local experience and professional judgement is critical for interpreting climate information and adaptation options.

Importantly, many actions that producers currently implement are likely to have climate adaptation benefits, and actions to promote climate change adaptation can complement producer motives as well as improve ecosystem services (Figure 2.1). The **Adaptation Strategies and Approaches** presented in Chapter 2 can be considered when enhancing existing farm or conservation practices or even adopting new structures, practices, or systems.

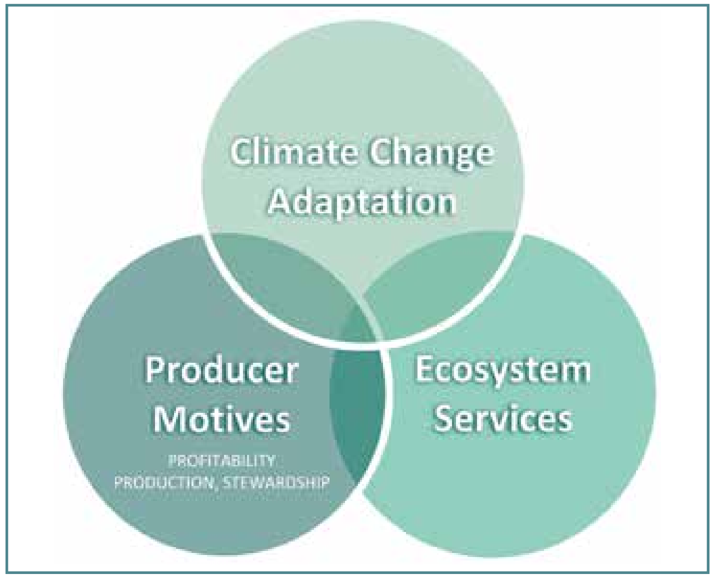


Figure 2.1 shows how actions for adapting agricultural systems to a changing climate complement producer motives and enhance ecosystem services. The first step for planning and implementing climate change adaptation is to look for these "win-win-win" opportunities.

Autonomous and Intentional Adaptation

The agricultural sector is dynamic and constantly changing. Although there is an increasing emphasis on adaptation to address climate variability and change, producers are always changing their actions in response to the changing environment around them. Farm practices and infrastructure are often adjusted in response to changing biophysical conditions, such as pests and diseases, as well as socioeconomic changes in markets, policies, and tariffs (Anwar et al. 2013; Smit and Skinner 2002).

Because of this continuous learning and improvement within many agricultural settings, many actions may have climate change adaptation benefits even if climate was not an explicit consideration in the decisionmaking (Schmidt et al. 2014). For example, a dairy farmer may decide to improve a barn to increase the building's cooling capacity based upon expected gains in milk production; this action may reduce the effects of rising temperatures even though the increased frequency of hot weather resulting from climate change was not a deliberate consideration. Many producers are likely to implement these "autonomous" adaptations (Anwar et al. 2013; Smit and Skinner 2002; Smit et al. 1999).

Box 2.2: Adaptation and Greenhouse Gas Mitigation Benefits

Climate change adaptation and greenhouse gas mitigation present two different, yet interrelated, human responses to climate change. As discussed in this chapter, adaptation actions work to reduce the vulnerability of natural or human systems to expected climate change effects and enable agriculture systems to cope with new and future conditions. Mitigation, in the context of climate change, results in the reduction of greenhouse gases present in the atmosphere. Greenhouse gas mitigation is particularly relevant to agriculture because of the emissions produced by the sector as a whole; agriculture accounted for 9 percent of national emissions in 2013 (U.S. EPA 2015). Greenhouse gas mitigation also presents opportunities for agriculture to sequester more carbon in healthy soils, which regulate water and nutrient cycling, buffer against adverse impacts such as erosion, and ultimately increase plant biomass production.

Greenhouse gas mitigation is a necessary component of an integrated climate change response sometimes referred to as climate smart agriculture. Moreover, it can help to reduce the amount of adaptation needed in the future by reducing the degree to which greenhouse gases disrupt the climate system. While this document focuses on actions that agricultural producers can take to enhance the ability of farms to adapt to changing conditions, it is important to note that many practices that help adapt farms to changing conditions also have mitigation benefits.

When evaluating adaptation responses, producers can decide to place additional emphasis on actions that also mitigate greenhouse gas emissions. For example, a producer using the **Adaptation Workbook** (Chapter 4) can identify management objectives for greenhouse gas mitigation, such as increasing soil organic carbon or reducing the use of nitrogen fertilizers that can convert to nitrous oxide, a powerful greenhouse gas.

Farm Practice	Adaptation Benefits	Mitigation Benefits
Use of cover crops	Increased soil cover and organic matter reduces water loss and the potential for drought stress; increased cover reduces erosion associated with extreme weather	Increased carbon sequestration in soils
Adjust nitrogen application rates to account for precipitation rates and local conditions (Moebius-Clune et al. 2010)	Reduces nitrogen leaching and denitrification that may occur with increasing amounts of spring precipitation	Lower levels of nitrogen fertilizer application reduce nitrous oxide losses from the fertilizer, as well as carbon dioxide emissions from fertilizer production
Use tree cover or silvopasture systems for livestock production (Schoeneberger et al. 2012)	Increases shading of livestock to reduce heat stress	Trees provide carbon sequestration

The intentional consideration of observed and expected changes in climate can help to further reduce risks to the productivity and profitability of farms and improve the stewardship of natural resources. Effective adaptation requires that producers and other land managers be intentional in the selection and implementation of adaptation actions (Stein et al. 2014). This intentionality specifically considers climate change impacts and vulnerabilities for the particular area of concern, and allows producers to design responses appropriately. For example, beef producers may recognize that the occurrence of drought is likely to continue increasing in their region and have their water well drilled deeper to ensure adequate livestock drinking water, or they might reduce their herd numbers to lower the drinking water demand. The **Adaptation Workbook** (Chapter 4) describes one process that can be used to explicitly consider climate change and develop intentional actions. Additional resources and tools may also be useful for assessing the future effects of climate change or for adapting agriculture and natural resource management planning and activities to expected future conditions (Box 2.3).

Short- and Long-Term Timeframes

It is important to identify actions for both near-term and long-term timeframes that help farmers adapt to changes in climate, as is done for changing markets, feed supply, regulations, and nearly all other farm operations (Schmidt et al. 2014; Takle et al. 2014). Producers typically rely on weather forecasts to make day-to-day decisions such as planting annual crops, pruning tree crops, managing nutrients and pests, and harvesting. Climate forecasts have the potential to play a large role in the decisionmaking and planning process especially for farmers' long term plans such as crop rotations, market and product changes, investments in infrastructure, farm succession, etc. (Takle et al. 2014). For example, corn growers may need to make seed purchases several months ahead of knowing field conditions at planting time while needing to secure rental

Box 2.3: Additional Adaptation Resources and Tools

The **Adaptation Workbook** outlined in Chapter 4 provides a structured but flexible process to consider the potential effects of climate change and variability in order to make climate-informed decisions for agricultural production and associated activities. Some decisions require specific tools to assess the effects of climate change over different future timeframes. Additionally, several other adaptation resources lay out similar processes or provide decision-support tools for adapting to climate change in agriculture as well as natural resource management:

- The Livestock and Poultry Environmental Learning Center offers guidance through the Animal Agriculture in a Changing Climate project. *Adapting to a Changing Climate: A Planning Guide* is available through eXtension at www.articles.extension.org/pages/69055/adaptation-and-risk-management.
- The U.S. Agency for International Development (USAID) and Catholic Relief Services offer guidance through the *Climate Change Adaptation Pocket Field Guide: Extension Practice for Agricultural Adaptation* available at www.meas-extension.org/meas-offers/training.
- USDA's National Climate Hub hosts the Climate Hubs Tool Shed, which provides access to tools from across the country to assist producers in adapting to climate variability and change available at www.climatehubs.oce.usda.gov/content/tools-and-data.
- An *Adaptation Workbook for Forest Management and Conservation* outlines a similar process for managing forests and other natural ecosystems. Access the online version of this workbook at www.adaptationworkbook.org.
- The National Wildlife Federation also has a *Guide to Climate Smart Conservation* to design and carry out wildlife conservation measures in the face of a rapidly changing climate. This guide is available at www.nwf.org/What-We-Do/Energy-and-Climate/Climate-Smart-Conservation/Guide-to-Climate-Smart-Conservation.aspx.

contracts or finances to purchase land a year or more before cropping takes place (Figure 2.2).

Several different frameworks exist for thinking about adaptation at multiple temporal scales, but all identify the need to consider both short-and long-term adaptation options and identify ways to accommodate increasing levels of change over time:

- Anwar et al. (2013) describe climate adaptation as a continuum of actions that range from short-term incremental change toward more substantive transformational actions. In this way, the short-term initiatives can inform longer term strategy through a "learn by doing" approach.
- Stokes and Howden (2010) describe a transition from incremental adaptations, which will eventually have a limited effectiveness under severe climate change, to more systemic and transformational change.
- Jarvis et al. (2011) describe a short-term focus on risk management to address issues related to food security, with a longer term shift toward progressive adaptation that facilitates change.
- Easterling (1996) describes an emphasis on short-term resilience to increase the capacity of systems to recover from disruptions, followed by long-term adaptation where the form and function of a system is deliberately altered.
- Schmidt et al. (2014) suggest that producers identify short-term "quick fixes" that utilize management or technology to reduce impacts, as well as long-range planned adaptations.

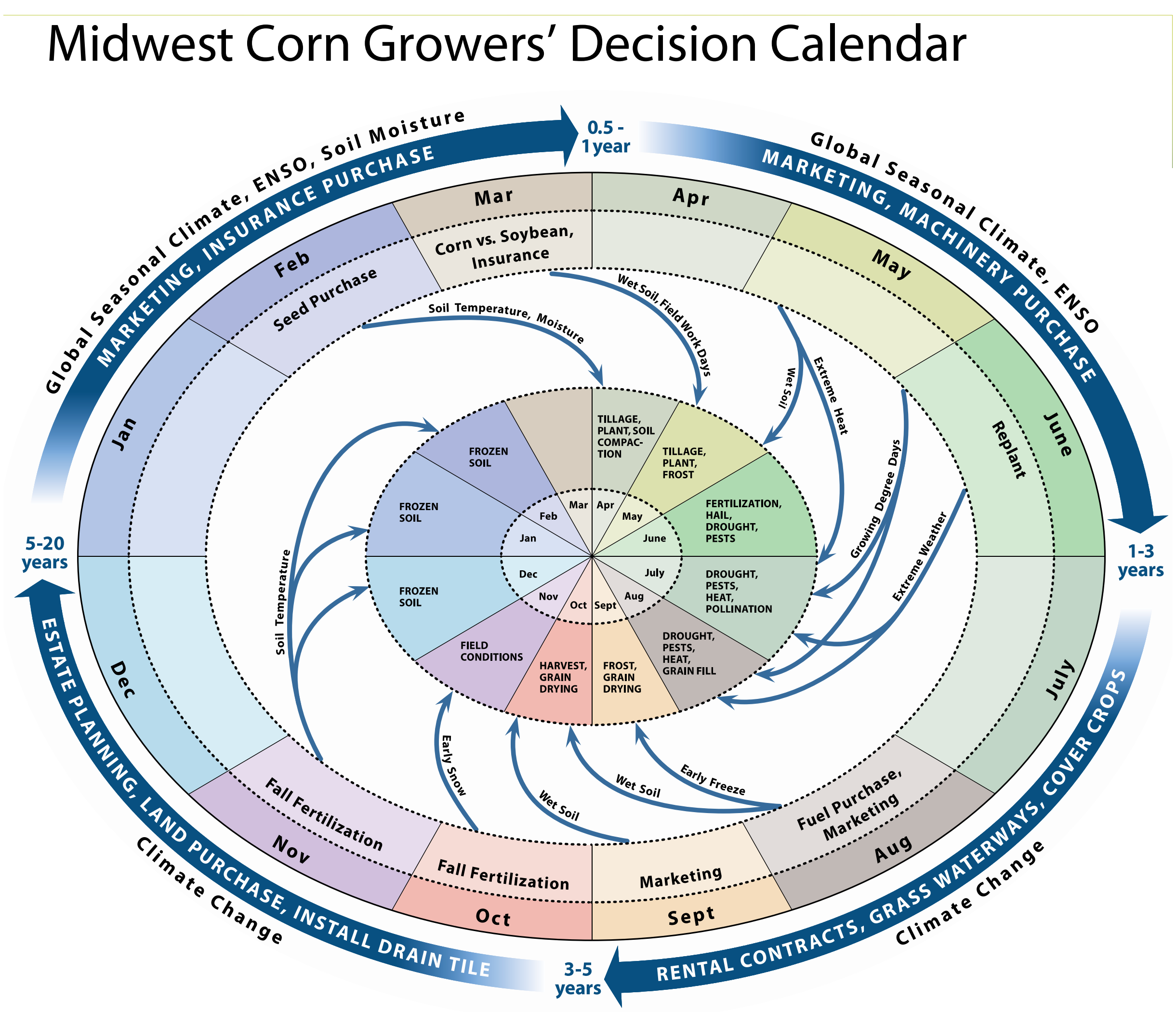


Figure 2.2 the Midwest Corn Grower's Decision Calendar shows an example of considerations over short- and long-term timeframes. Source: Takle et al. (2014).

Managing for Persistence and Change

Adaptation responses will vary widely, from actions that maintain existing conditions all the way through to transformational changes to the farm, such as changing production systems or even the lands used to produce commodities. This continuum can be roughly categorized into two contrasting options for responding to climate change: managing for persistence versus managing for change (Stein et al. 2014) (Figure 2.3).

- **Managing for persistence** generally focuses on maintaining the current system by reducing the climate change impacts that are pushing it in an unproductive direction. This includes actions to increase the resistance of a farm or agricultural system to change, as well as actions that increase its resilience (i.e., ability to bounce back) from disruptions.
- **Managing for change** moves farm activities toward the new conditions created by climate change. Managing for change can range from small changes such as trying out new crop or livestock species that are better suited to warmer climates, to major changes that fundamentally transform farm operations.

Managing for persistence and for change are not mutually exclusive ideas, and any farm enterprise may do some of both. Further, there are instances where a nearer term focus on managing impacts and maintaining current conditions sets up a longer term plan to change management goals and practices. For example, a farmer could focus on maintaining the current rotation of field crops and use cover crops to build better soils before shifting to an entirely new cropping system. The **Adaptation Strategies and Approaches** presented in the next chapter describe a diverse menu of adaptation responses that producers can use to intentionally develop customized actions based on their needs.

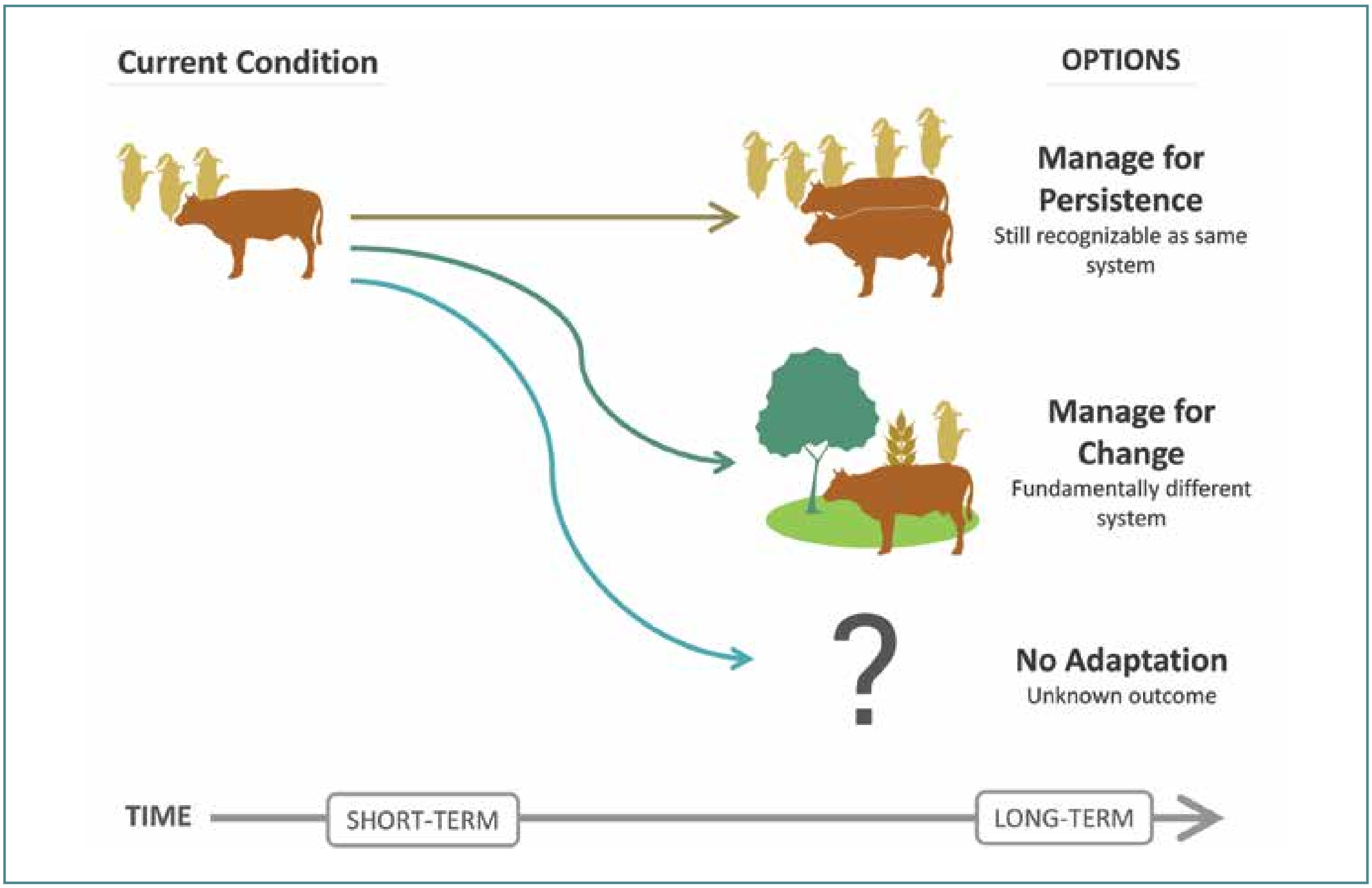


Figure 2.3. An illustration of adaptation options to manage for persistence and change, as well as no adaptation, over short- and long-term timeframes. Note that producers can switch options at any point, such as managing for persistence until conditions meet a threshold where change is preferable.

CHAPTER 3:
Adaptation Strategies and Approaches

One of the major challenges of adapting agricultural systems to climate change is translating broad science-based concepts of climate adaptation (Chapter 2) into specific, tangible on-farm actions. This chapter addresses that challenge by providing a synthesis of adaptation responses from the literature, which are organized in a tiered structure from broad concepts to specific actions (Figure 3.1). Eight broad strategies, each with their own more specific approaches, were synthesized from dozens of scientific papers that discussed adaptation actions at a variety of scales and locations. The strategies and approaches were reviewed by a diverse pool of producers, researchers, and other professionals from across the Midwest and Northeast (Appendix 1) and are broadly applicable across a diversity of commodities and production systems. These strategies and approaches are designed to serve as "stepping stones" to enable producers to understand the rationale for making decisions and taking appropriate actions to adapt to climate variability and change (Box 3.1).

The adaptation strategies and approaches are presented as a menu of possible adaptation responses that producers may consider. By using the **Adaptation Workbook** (Chapter 4), producers can select relevant adaptation strategies and

Figure 3.1. Adaptation strategies, approaches, and tactics address different levels of specificity and decisionmaking.

Box 3.1:
Using the Adaptation Strategies and Approaches Menu

The adaptation strategies and approaches menu can provide:

- A full spectrum of possible adaptation responses that can help sustain viable agricultural systems or transform unviable ones to meet the challenges of climate change,
- A menu of adaptation strategies and approaches from which producers can better understand the rational for making decisions and develop tactical actions best suited to meeting their goals and needs,
- Examples of tactics to implement an approach, recognizing that the producer will design specific actions, and
- A platform for discussing climate change-related topics and adaptation methods.

The adaptation strategies and approaches do not:

- Make recommendations or set guidelines for management decisions. It is up to the producer to decide how this information is used.
- Express preference for any strategies or approaches within a particular agricultural system, location, or situation. Rather, a combination of location-specific factors and professional/landowner expertise informs the selection of any strategy or approach.

approaches, and adjust and refine these to develop their own prescriptive tactics to achieve a specific management objective in a specific location. Examples of tactics are provided in order to convey a sense of the diverse ways in which the adaptation strategies and approaches may be implemented, with an emphasis on actions relevant to farms and expected climate change in the Midwest and Northeast.

A Menu of Adaptation Responses

Information on how to increase resilience to or take advantage of the anticipated effects of climate change in agricultural systems is rapidly growing (Howden et al. 2007). Much of this information, however, remains broad and generic, providing insufficient detail to enable producers to identify specific actions that facilitate adaptation while meeting production goals and objectives. Because agriculture encompasses an immense diversity of commodities, crops, and practices across even more diverse geographic and environmental conditions, potential adaptation responses are equally numerous (Howden et al. 2007).

Adaptation responses vary in specificity, from general concepts to specific actions (Janowiak et al. 2011) (Figure 3.1). Adaptation ***strategies*** are abundant in recent literature and can be broadly applied in many ways across a number of landscapes and systems. ***Approaches*** are more specific, describing how strategies can be employed. Differences in application among different agricultural systems and landowner goals start to become evident. Ultimately, ***tactics*** are the most specific adaptation responses, providing prescriptive direction about what actions can be applied on the ground, and how, where, and when. We have provided examples of tactics for each approach, but we do not intend that they be implemented without due consideration of all relevant factors. Tactics are developed in relation to the particular system or crop, site conditions, landowner goals, markets, and other factors.

Managing fields and farms at the landscape scale.

This set of adaptation strategies and approaches serves as a *menu* of potential adaptation responses derived from the literature and expert feedback (Box 3.2). It helps producers identify their adaptation intentions and supports them in developing and implementing their own specific adaptation actions that are most suitable to their particular situation. Although menu items can be applied in various combinations to achieve desired outcomes, not all items on the menu will work together. Furthermore, actions that work well in one location or with a particular crop or system type may not work in another; it is up to the producer to decide what actions will work best for them.

Importantly, the adaptation strategies and approaches included in this resource build upon current farm practices and conservation actions that work to sustain and conserve working lands over the long term. Many conservation activities already promote system health and resilience. Likewise, many adaptation actions are consistent with sustainable management and efforts to restore system function and integrity. A changing climate may compel some producers to enhance existing practices or adopt new ones, but it can also underscore the importance of sustainable practices that may already be in use.

Box 3.2: Menu of Adaptation Strategies and Approaches

Strategy 1:	**Sustain fundamental functions of soil and water.**
Approach 1.1:	Maintain and improve soil health.
Approach 1.2:	Protect water quality.
Approach 1.3:	Match practices to water supply and demand.
Strategy 2:	**Reduce existing stressors of crops and livestock.**
Approach 2.1:	Reduce the impacts of pests and pathogens on crops.
Approach 2.2:	Reduce competition from weedy and invasive species.
Approach 2.3:	Maintain livestock health and performance.
Strategy 3:	**Reduce risks from warmer and drier conditions.**
Approach 3.1:	Adjust the timing or location of on-farm activities.
Approach 3.2:	Manage crops to cope with warmer and drier conditions.
Approach 3.3:	Manage livestock to cope with warmer and drier conditions.
Strategy 4:	**Reduce the risk and long-term impacts of extreme weather.**
Approach 4.1:	Reduce peak flow, runoff velocity, and soil erosion.
Approach 4.2:	Reduce severity or extent of water-saturated soil and flood damage.
Approach 4.3:	Reduce severity or extent of wind damage to soils and crops.
Strategy 5:	**Manage farms and fields as part of a larger landscape.**
Approach 5.1:	Maintain or restore natural ecosystems.
Approach 5.2:	Promote biological diversity across the landscape.
Approach 5.3:	Enhance landscape connectivity.
Strategy 6:	**Alter management to accommodate expected future conditions.**
Approach 6.1:	Diversify crop or livestock species, varieties or breeds, or products.
Approach 6.2:	Diversify existing systems with new combinations of varieties or breeds.
Approach 6.3:	Switch to commodities expected to be better suited to future conditions.
Strategy 7:	**Alter agricultural systems or lands to new climate conditions.**
Approach 7.1:	Minimize potential impacts following disturbance.
Approach 7.2:	Realign severely altered systems toward future conditions.
Approach 7.3:	Alter lands in agricultural production.
Strategy 8:	**Alter infrastructure to match new and expected conditions.**
Approach 8.1:	Expand or improve water systems to match water demand and supply.
Approach 8.2:	Use structures to increase environmental control for plant crops.
Approach 8.3:	Improve or develop structures to reduce animal heat stress.
Approach 8.4:	Match infrastructure and equipment to new and expected conditions.

Strategy 1: Sustain fundamental functions of soil and water.

Climate has the potential to disrupt critical functions of soil and water, and many management actions will be needed to work both directly and indirectly to maintain the integrity of agricultural systems in the face of climate change. Many existing guidelines and conservation practices describe actions to reduce impacts to soil and water; many of these actions are also likely to be beneficial in the context of adaptation, either in their current form or with modifications to address potential climate change impacts.

Approach 1.1: Maintain and improve soil health.

Healthy soils are necessary to ensure the productivity and profitability of diverse agricultural enterprises. Healthy soils provide for many functions (Freidman et al. 2001) and ecosystem services (Palm et al. 2014), including: sustaining biological activity and diversity, regulation of water quality and quantity, provision of nutrients, and carbon sequestration. These functions and services depend on the physical, chemical, and biological characteristics or properties of the soil, some of which are dynamic and easily altered, while others are inherent and more resistant to change. Climate change creates multiple direct and indirect threats on soil health, which in turn creates challenges for agricultural productivity. Practices that improve soil health help to buffer many of these impacts. For example, crop residues and soil organic matter can help protect against both dry and wet precipitation extremes; increased organic matter can improve water infiltration and reduce nutrient losses during extreme precipitation events as well as retain moisture in the soil during dry conditions (Food and Agriculture Organization of the United Nations 2007; Anwar et al. 2013). Altering the land use production system or infrastructure may also maintain and improve either dynamic or inherent soil properties. Approaches for Strategy 7 (Alter agriculture systems or lands) and Strategy 8 (Alter infrastructure to match new and expected conditions) provide examples of these types of adaptation tactics.

Example Adaptation Tactics

For all farming activities at risk of causing soil disturbance, usually typical of annual field, forage, vegetable, and small fruit production, as well as during establishment of pastures, orchards, vineyards, or plantations:

- Minimize soil disturbance by avoiding or reducing tillage for planting, weed control, or other purposes
- Provide nearly year-round ground cover of residue or plants to reduce soil exposure to erosive forces of water and wind (Derner et al. 2015)
- Increase soil organic matter to improve soil water-holding capacity, soil structure, and water infiltration, and to reduce erosion (use cover crops and mixes, crop or livestock residues, compost, mulch, biochar, or other organic amendments) (Shea 2014)
- Diversify crop rotations to include plant species of different functional groups for improving below-ground conditions for soil life and address threats from disease, weed, and insect pests.
- Shift planting dates to avoid field operations during wet conditions (Wolfe et al. 2011)
- Control vehicle traffic to minimize soil compaction by equipment
- Integrate grazing to further improve soil biology
- Consider windbreaks where soil erosion by wind is a concern
- Consider land leveling or subsurface drainage under the Approaches listed for Strategy 8: Alter infrastructure if altering inherent soil properties like soil surface topography and drainage are feasible.

Additional example tactics for established pastures or other perennial crop land use systems:

- Manage grazing rest periods, stocking densities, and rotational intensity
- Manage rates and timing of harvesting hay, biomass, or other similar herbaceous perennial crops

Approach 1.2: Protect water quality.

Fresh clean water is vital to all living things. Because agricultural practices can affect aquifers and water sources, on-farm as well as downstream from the farm, it is important that practices protect water quality through the entire cycle. Anticipated alterations of the water cycle due to climate change will have wide-ranging effects on agricultural production, depending on the farm location, the type of agricultural system, and the type of change. For example, increases in precipitation during some times of the year could increase runoff of fertilizers or effluents, increasing issues with excess nitrogen or other nutrients in downstream water bodies. This approach focuses on additional agricultural practices needed in the field beyond those listed in Approach 1.1 (Maintain and improve soil health). Strategy 4 (Reduce the risk and long-term impacts of extreme weather) suggests responses specifically for extreme precipitation events.

Example Adaptation Tactics

For all cropping activities at risk of causing water pollution, usually typical of nutrient and pesticide applications in annual and perennial field and forage crop, vegetable, tree, berry, and vine fruit production:

- Reassess nutrient applications and ensure that use of organic materials, fertilizers, amendments, and all sources of nutrients is matched to changing climate conditions (Howden et al. 2007)
- Reassess pesticide risk and ensure that all pesticide applications consider changing climate conditions (Donald et al. 2005)
- Manage water to prevent ponding, running, erosion, and nutrient leaching where rainfall increases (Howden et al. 2007). Typical water management practices include diversions, terraces, waterways, grade stabilization structures, etc.

Confined animal agriculture, greenhouse, nursery, and mushroom production:

- Divert clean water from areas at risk for contamination
- Minimize the effects of agricultural waste on surface and ground water resources

Approach 1.3: Match management practices to water supply and demand.

The agriculture sector uses a substantial amount of ground and surface water resources in the United States. Agriculture also sometimes competes for the same water resources as urban and industrial demands, and climate change has the potential to alter both water availability and demand (Elliott et al. 2014; Taylor et al. 2013). Warmer temperatures increase water loss through evaporation and plant transpiration such that more water is generally needed to maintain productivity under warmed conditions. Further, altered precipitation patterns have the potential to increase water demand where the amount of precipitation decreases or where precipitation is concentrated into fewer, more intense events. On-farm water stewardship can extend the availability of water under changed climate conditions. (Ames and Dufour 2014). To be effective, this approach must build upon the practices used in the field to improve the water infiltration function of the soil as listed in Approach 1.1 (Maintain and improve soil health.). This approach emphasizes practices and technologies for on-farm water management to improve the efficiency of water use in order to sustain water supplies over the long term. More substantial changes may require investments in new infrastructure, which are described in Strategy 8 (Alter infrastructure to accommodate new and expected conditions).

Example Adaptation Tactics

For all cropping activities using substantial water quantities, typical of irrigated cropping systems:

- Where soils have adequate infiltration rates and evaporation rates are minimized, increase irrigation capacity, particularly for high-value crops (Wolfe et al. 2011)
- Improve irrigation efficiency for water conveyance and application with latest technology such as micro or drip irrigation (Ames and Dufour 2014, Derner et al. 2015)
- "Water-bank" by using less irrigation in non-drought years, saving water for use in drought years, and creating markets to lease conserved water to municipalities to balance agricultural and municipal water needs. (Derner et al. 2015, Schwabe and Connor 2012)
- Increase planting density with irrigation and improved soil fertility management (Blanc and Reilly 2015)
- Wider use of technologies to ''harvest'' water, conserve soil moisture (e.g., crop residue retention), and use and transport water more effectively where rainfall decreases (Howden et al. 2007)
- Use new technology for subsurface irrigation, and irrigate with gray or reclaimed water to reduce water use. (Derner et al. 2015)

Strategy 2: Reduce existing stressors of crops and livestock.

Climate change is likely to increase stress on agricultural systems through a variety of direct and indirect effects (Walthall et al. 2012). Changes in temperature and other climatic conditions will have numerous impacts on agricultural systems (Pryor et al. 2014; Horton et al. 2014). Systems may already be performing poorly because of stressors like insect pests, pathogens, or competing species, which can make agricultural commodities more susceptible to impacts from climate change. Reducing stressors of agricultural commodities that are presently unaffected or indirectly affected by climatic stressors will often increase the ability of the system to cope with future changes in climate.

Approach 2.1: Reduce the impacts of insect pests and pathogens on crops.

Even modest changes in climate may cause substantial increases in the distribution and abundance of many insect pests and pathogens (Hatfield et al. 2015; Tobin et al. 2015), potentially leading to reduced productivity or increased plant stress and mortality. Climate change impacts may exacerbate other stressors, site conditions, and interactions among these factors and increase vulnerability to these agents. This approach emphasizes actions to be taken on site within the field, while Strategy 5 (Manage farms and fields as part of a larger landscape) suggests complementary tactics needed across the landscape.

Example Adaptation Tactics

For all cropping activities at risk to adverse impacts from insect pests and pathogens:

- Increased scouting for pests and pathogens (Schmidt et al. 2014)
- Enhanced use of integrated pest management (IPM) (Wolfe et al. 2011, Tobin et al. 2015)
- Improved rapid response plans and regional monitoring efforts to allow for targeted control of new pests before they become established (Wolfe et al. 2011)
- Use of varieties and species resistant to pests and diseases (Howden et al. 2007)
- Altering crop rotations (Shea 2014; Schmidt et al. 2014)
- Longer cropping systems (greater diversity and longer rotations)

Approach 2.2: Reduce competition from weedy and invasive species.
Climate change is expected to increase the potential habitat for many weedy and invasive plant species (Hatfield et al. 2015; Tobin et al. 2015), which may increase competition among plants for light, water, and nutrients. Although plant productivity may increase because of the positive effects of carbon dioxide fertilization and longer growing seasons, not all species will be able to take equal advantage of these positive impacts (Rosenzweig et al. 2014; Ziska et al. 2012), and the competitive relationships between weeds and crops may change with some weeds gaining an advantage (Ziska and Bunce 1997; Valerio et al. 2013). Reducing competition for resources can enhance the persistence of desired species and increase the ability of systems to cope with the direct and indirect effects of climate change. Management of highly mobile invasive species may require increased scouting and coordination across property boundaries, and it will likely require an increasing budget for control efforts.

Example Adaptation Tactics

For all crop production activities (field, forage, small fruit and vegetables, orchards, etc.) at risk for increased competition from weeds and invasive species:

- Increased scouting for weedy species
- Increased use of integrated pest management (IPM) strategies (prevention, avoidance, monitoring, and suppression) to prevent economic crop damage from weeds, minimize resistance in weeds, and prevent or mitigate unnecessary risks to natural resources and humans
- Eradication of noxious weeds
- Control or eradication of other invasive plant species adversely impacting desired plant community

Approach 2.3: Maintain livestock health and performance.
Climate change is expected to affect livestock production by increasing animal stress from diverse changes that include higher temperatures, changes in forage quality and quantity, and increases in pest and pathogen incidence (Walthall et al. 2012). This approach works to reduce the risks associated with livestock production systems by maintaining animal performance levels and reducing the negative impacts of environmental changes that increase animal vulnerability. The risks to livestock systems increase when performance levels drop, for any reason, making them more vulnerable to other changes in environmental parameters (Hahn et al. 2005). Maintaining adequate livestock health and performance prepares animals to cope better with changing and extreme conditions.

Example Adaptation Tactics

For animal production activities (dairy, beef, poultry, swine, other) vulnerable to normal environmental parameters and as applicable to the species:

- Maintain adequate nutrition and access to adequate exercise, clean housing, water, and feed supplies.
- Prevent infectious disease and control parasites by preventing contact with wildlife.
- Follow recommended veterinary practices and biosecurity procedures.

Strategy 3: Reduce risks from warmer and drier conditions.

Many of the key climate variables affecting agricultural productivity are directly tied to increases in temperature (Hatfield et al. 2014). A longer growing season, warmer daytime and nighttime temperatures, and drier conditions are all expected to have important effects on agricultural crops and livestock, and in many areas of the Midwest, effects are already being observed (Hatfield et al. 2014). Increasingly, producers will need to consider and address the unique effects of higher temperatures on individual commodities. In some locations, drier conditions will have greater impacts.

Approach 3.1: Adjust the timing or location of on-farm activities.

As the climate changes, consider adjusting farm practices to take into account altered seasonality. Producers have always made adjustments to cope with variable weather conditions by changing the timing or field operations (Hatfield et al. 2014), and many of these types of changes are already occurring autonomously as conditions change and without specific consideration of longer term climate trends (Smit and Skinner 2002). In fact, evidence suggests that decisions about the timing of many agricultural practices are more likely to be based upon recent years' weather than the longer term trend for a particular place (Smit et al. 1996). This approach emphasizes alterations in the timing and location of on-farm activities that take into account long-term trends and projections in climate, as well as inter-annual variation of weather. Although broader scale changes in location and timing will also be needed, such as northward shifts of crops to new landscapes (Ainsworth and Ort 2010), these are beyond the scope of this approach.

Example Adaptation Tactics

Field and forage crops and vegetables, nursery, tree, berry and vine fruit production as applicable:

- Adjust timing of planting, such as earlier planting dates to take account of longer growing season (Anwar et al. 2013, Wolfe et al. 2011, Tobin et al. 2015, European Commission 2009)
- Adjust timing or sequencing of cropping operations, such as altering amount of timing of irrigation or fertilizer application (Howden et al. 2007)
- Match crops to local conditions, such as on slope, aspect, or microsite (Ames and Dufour 2014)
- Plant two successive crops to take advantage of a single growing season (double-cropping) and increase annual production
- Adjust synchronization of crop nitrogen (N) needs and application for improved nitrogen use efficiency (Kanter et al. 2015)

Animal agriculture:

- Adjust the timing of grazing and pasture use to forage availability for livestock (Howden et al. 2007, Derner et al. 2015)
- Alter the timing of animal reproduction to match suitable temperatures and feed availability (Howden et al. 2007, Derner et al. 2015)

Vegetables, nursery crops, tree, berry, and vine fruits:

- Implement techniques to prevent frosting, recognizing that cold temperatures and extremes will still occur (Tobin et al. 2015)

Approach 3.2: Manage crops to cope with warmer and drier conditions.

Since the Midwest and Northeast regions of the United States can expect to see warmer temperatures and seasonal changes in precipitation, it is reasonable to expect that soil moisture regimes will also shift. Although there is substantial variation among model projections, longer growing seasons and warmer temperatures are generally expected to result in greater evapotranspiration losses and lower soil-water availability later in the growing season (Hayhoe et al. 2007; Gutowski et al. 2008; Kunkel et al. 2013b; Kunkel et al. 2013a). Further, increases in extreme rain events suggest that greater amounts of precipitation may occur during fewer precipitation events, resulting in longer periods between rainfall (Karl et al. 2008). The effects of warmer temperatures on photosynthesis is one of the biggest determinants of crop yields, and temperatures only slightly above optimum can cause mild heat stress and begin to inhibit photosynthesis (Ainsworth and Ort 2010). This approach emphasizes the management of existing crops while Strategy 6 (Alter management to accommodate new and expected conditions) presents example actions to diversify crops or switch to new crops. The effectiveness of actions under this approach are highly interrelated and dependent on adequately functioning soil and water crop resources addressed by actions in Strategy 1 (Sustain fundamental functions of soil and water).

Example Adaptation Tactics

For cropping activities :

- Select longer growing-season, heat-resistant, or drought-resistant varieties of crops (Wolfe et al. 2011)
- Adjust timing of planting, such as earlier planting dates, to avoid heat stress during critical periods of plant development (Anwar et al. 2013, Wolfe et al. 2015)
- Alter plant population density to reduce crop demands for water or nutrients

- Increase the efficiency of irrigation systems and water transportation (Derner et al, 2015, Howden et al. 2007)
- Increase soil cover (mulch, cover crop) to conserve soil moisture and reduce soil temperatures (Ames and Dufour 2014, Howden et al. 2007)
- Improve use of seasonal and short-term weather forecasts (World Meteorological Organization (WMO) and Global Water Partnership (GWP) 2014)

Approach 3.3: Manage livestock to cope with warmer and drier conditions.
As with crops, altered climate conditions will affect livestock production. Climate can affect animal agriculture through changes in feed grain production, pasture and forage crop production, animal productivity, and disease and pest issues (Hatfield et al. 2014). In particular, livestock respond to changes in temperature by altering their core body temperature, metabolic rates, or behavior, all of which can lead to increased stress and disrupt their growth, production, or reproduction. (Hatfield et al. 2014). This approach emphasizes actions that manage the current livestock systems. Strategy 6 (Alter management to accommodate new and expected conditions) describes actions to transition to new breeds or systems while Strategy 8 (Alter infrastructure to accommodate new and expected conditions) describes the use of infrastructure such as fans or misters to cool animals.

Example Adaptation Tactics

For animal agriculture:

- Provide partial to total shelter to reduce heat stress associated with extreme heat. (Derner et al. 2015)
- Increase available shade for pastured animals (25x’25 Alliance Adaptation Work Group 2013)
- Alter grazing management practices or rotations to match stock rates to forage production, such as by moving cattle to fresh pasture at night (Derner et al. 2015, Tobin et al. 2015, Howden et al. 2007)
- Use grass or fodder banks (resting of pastures for >1 year) to provide forage during dry periods (Derner et al. 2015, Anwar et al. 2012)
- Alter the timing or placement of feeder animals and subsequent finishing time of these animals to reduce stress associated with heat waves (Derner et al. 2015)
- Alter livestock stocking rates (Anwar et al. 2012)
- Select more heat-tolerant breeds (25x’25 Alliance Adaptation Work Group 2013)
- Increase herd disease surveillance in livestock (25x’25 Alliance Adaptation Work Group 2013)
- Make additional fresh, clean water available (25x’25 Alliance Adaptation Work Group 2013)
- Alter animal diets, such as by switching rations from forage to other feed, use of supplementary feeds and concentrates, or feed conservation (25x’25 Alliance Adaptation Work Group 2013, Anwar et al. 2013, Howden et al. 2007)
- Monitor animal temperatures to provide early warning of stress

Strategy 4:
Reduce the risk and long-term impacts of extreme weather.

Climate change increases overall climate variability (Intergovernmental Panel on Climate Change (IPCC) 2012; Kunkel et al. 2012; Peterson et al. 2013). In addition, climate change is expected to increase the likelihood of extreme weather including extreme precipitation and storms, which will increasingly challenge agricultural activity (Walthall et al. 2012). Further, extreme cold, snow, and other winter conditions will continue to persist—or even increase, such as with mid-latitude snow in some areas—for many decades into the future. Even as trends continue to emerge, responses will need to adjust appropriately to the changes in extreme weather. Adaptation actions that improve the capacity to adapt to enhanced weather variability, and extreme events in particular, will generally improve overall climate change preparedness (Bradshaw et al. 2004).

Approach 4.1: Reduce peak flow, runoff velocity, and soil erosion.
The number of weather- or climate-related disasters costing more than $1 billion is increasing nationwide, and many of these disasters involve extreme precipitation or resulting floods. An increase of extreme precipitation events increases risk of damage to soils, crops, and infrastructure. Increases in runoff flow volume and velocity following severe precipitation events can lead to an increase in soil erosion, although the risk of soil erosion, nutrient runoff and other impacts on a specific site ultimately depend on local soil and landscape conditions. To reduce impacts of extreme precipitation events on soil and water resources, take actions to reduce their flashiness and slow the flow of water across the landscape. This approach builds on actions developed under Strategy 1 (Sustain fundamental functions of soil and water) in order to maintain and improve soil health and protect water quality in response to higher peak flows, runoff velocities, and soil erosion resulting from increasingly severe storm events. If the cost of these enhancements or risks of failure become prohibitive, actions to alter management, systems, or infrastructure (Strategies 6, 7, and 8) may also be suitable.

Example Adaptation Tactics

For annual cropping activities:

- Diversify existing annual cropping systems with new combinations of annual crop species or varieties more resistant to higher peak flows, runoff velocities, and erosion.
- Convert in-field areas at high risk of flow erosion and pollution transport to perennial crops (grass, shrub, or tree crops); pasture/grazing lands, forest cover, or conservation buffers suitable to conveying water.

Animal agriculture and associated agriculture lands:

- Diversify existing forage crops with new combinations of forage species or varieties more resistant to higher peak flows, runoff velocities, and erosion.
- Use wetlands, buffer strips, swales, and other landscape features to buffer against hydrologic variability and increase infiltration after extreme precipitation events (Ames and Dufour 2014; 25x'25 Alliance Adaptation Work Group 2013).
- Maintain or improve infrastructure (water conveyances, lanes, roads, culverts, ponds, waste storage facilities, rooves and covers, roof runoff structures, heavy use areas, etc.) to accommodate more intense precipitation events.

Approach 4.2: Reduce severity or extent of water-saturated soil and flood damage.

More extreme precipitation events also increase the frequency for flooding or standing water in low-lying and susceptible areas (Walsh et al. 2014). Extended periods of excess water during the growing period can lead to yield declines or crop losses. Wet soils can also hinder field operations and animal agriculture activities like grazing or exercise. This approach builds on actions developed in Strategy 1 (Sustain fundamental functions of soil and water) in order to maintain and improve the soil's function to infiltrate water and protect water quality in response to higher peak flows, runoff velocities, and soil erosion resulting from increasingly severe storm events. If the cost of these enhancements or risks of failure become prohibitive, actions to alter management, systems, or infrastructure (Strategies 6, 7, and 8) may also be suitable.

Example Adaptation Tactics

Cropping and animal agriculture activities:

- Shift production zones away from flood-prone areas (Tobin et al. 2015)
- Shift to more flood-tolerant varieties or crops (Wolfe et al. 2011)
- Use new field drainage practices to reduce excess seasonal soil water conditions, such as tile drainage or flashboard risers, to adjust water drainage outlets (Derner et al. 2015, Wolfe et al. 2011, 25 by '25 Alliance, Morton et al. 2015)

Approach 4.3: Reduce severity or extent of wind damage to soils and crops.

While wind events and the ensuing effects on agricultural crops and systems may become more frequent and severe under climate change, there are many challenges in predicting the size, frequency, and intensity of these events (Kunkel et al. 2012; Peterson et al. 2013). Some lands may be particularly susceptible to projected increases in storm intensity. Conservation techniques exist to reduce the exposure of sensitive crops to wind.

Example Adaptation Tactics

Cropping activities:

- Maintain crop residues to reduce exposure of young sensitive crops to damaging winds
- Cover the soil with crop residues or cover crops to protect it from erosive winds
- Install windbreaks, hedgerows, or vegetative wind barriers to reduce wind exposure for sensitive crops

Strategy 5: Manage farms and fields as part of a larger landscape.

Individual farms, fields pastures, and grazing lands are part of a larger, landscape-level agroecosystem that provides critical ecosystem services and non-commodity goods in addition to agricultural products (McGranahan 2014). Because of the global nature of climate change, impacts will be observed across landscapes and regions. Actions to increase landscape diversity and connectivity can increase the ability of systems to adapt to changing environmental conditions and stresses (Food and Agriculture Organization of the United Nations 2007; Liebman and Schulte 2015; McGranahan 2014). While the ability of individual producers to affect landscape-level change will vary widely, the integration of landscape considerations into farm management may help to increase adaptive capacity of the agriculture sector in the long term.

Approach 5.1: Maintain or restore natural ecosystems. In the context of climate change, actions to maintain and restore natural ecosystems can help to protect key ecosystem features on the landscape, fostering a diversity of species and ecological functions (Stein et al. 2014). While land that is maintained in natural systems is not available for farm production, there is evidence that the integration of natural ecosystems with agricultural production lands can have notable benefits to soil and water quality without substantially reducing agricultural production (Schulte Moore 2014). Farm operations often include incidental areas, such as idle center pivot corners, odd areas, ditches and watercourses, riparian areas, field edges, seasonal and permanent wetlands, and other similar areas not purposefully managed for food, forage, or fiber production. These incidental areas are typically near to and associated with agriculture production or conservation lands. They may be functional natural ecosystems, but more typically are degraded and have substantial opportunity to diversify and improve ecosystem services.

Example Adaptation Tactics

Nearby non-agricultural lands:

- Maintain or restore riparian areas, wetlands, bottomlands, and floodplains
- Maintain and enhance species and structural diversity by promoting diverse vegetation types and retaining natural ecosystems and biological legacies (Swanston and Janowiak 2012)
- Restore or maintain fire in fire-adapted ecosystems. (Swanston and Janowiak 2012)

Approach 5.2: Promote biological diversity across the landscape.
A diversity of species and structures across a landscape may help to reduce the susceptibility of its individual components to climate change, as well as other changing environmental conditions and stressors (Peterson et al. 1998; Food and Agriculture Organization of the United Nations 2007; Liebman and Schulte 2015; McGranahan 2014). Although many agricultural systems are inherently low in diversity to maximize production, risk can be reduced by fostering diversity across landscapes (Liebman and Schulte 2015; Schulte Moore 2014). At a landscape level, natural ecosystems and naturalized settings (e.g., field borders, native plantings, etc.) can increase environmental services such as water quality, wildlife abundance, pollinator habitat, and carbon sequestration (Liebman and Schulte 2015). Trade-offs to consider include good agricultural practices (GAP) required to prevent bird and similar wildlife disease vectors and as required for food safety inspections.

Example Adaptation Tactics

Nearby non-agricultural lands:

- Increase managed habitats across a range of landscapes (Swanston and Janowiak 2012b, Stein et al. 2014)
- Protect at-risk species and habitats (Swanston and Janowiak 2012b, Stein et al. 2014)
- Maintain or create refugia (Swanston and Janowiak 2012b, Stein et al. 2014)
- Create habitat for pollinators or other beneficial organisms

Approach 5.3: Enhance landscape connectivity.
Connections across natural ecosystems also enable large-scale adaptation by creating a mosaic of habitats to support natural and facilitated migrations of plants, animals, and other organisms across the landscape (Stein et al. 2014). While species migration is a critical factor in the maintenance of natural ecosystem function in a changing climate, the fragmentation of landscapes and loss of habitat may restrict species movements and gene flow (Davis and Shaw 2001; Iverson et al. 2004a). Many species are not expected to be able to migrate at a rate sufficient to keep up with climate change and associated range shifts (Davis and Shaw 2001; Iverson et al. 2004a). Increasing landscape connectivity may help species to migrate without additional assistance by allowing for easier species movement, reducing lags in migration, and enhancing the flow of genetic material (Heller and Zavaleta 2009; Stein et al. 2014).

Example Adaptation Tactics

Nearby non-agricultural lands:

- Use landscape-scale planning and partnerships to reduce fragmentation and enhance connectivity (Swanston and Janowiak 2012b)
- Maintain and create naturalized habitat corridors

Strategy 6: Alter management to accommodate expected future conditions.

As climate change impacts and risks increase, there will be a greater need to move from short-term, reactive adjustments toward more intentional, planned adaptation responses that are likely to create significant shifts in management (Smit and Skinner 2002). While adaptation actions vary widely in intent, timing, and scale, this strategy emphasizes a clear shift toward more substantial changes that ultimately transform the activities for a particular farm or producer.

Approach 6.1: Diversify crop or livestock species, varieties or breeds, or products.

Farm-level diversification can reduce the risk of climate change impacts on a farm, thereby lowering the economic risks associated with lower yields or market fluctuations (Bradshaw et al. 2004; Ames and Dufour 2014). At the same time, there can be costs to diversification, especially in the near term, due to the start-up costs and learning needed to initiate a new crop, as well as reduced economies of scale (Bradshaw et al. 2004). This approach may be used by diversifying commodities that are currently used within a current geographic area, or used in conjunction with the approaches below to diversify farms using plants and animals that are to be better adapted to future conditions.

Example Adaptation Tactics

All agriculture as applicable:

- Add additional farming activities or new commodities to diversify farm products and revenue
- Increase the representation of varieties, breeds, genetic sources, or species among commodities (Derner et al 2015)
- Diversity animal products or ages, such as including both cow-calves and yearlings (Derner et al 2015)
- Diversify varieties or breeds for different tolerances of cold hardiness, drought and heat tolerance, or other attributes (Ames and Dufour 2014, Anwar et al. 2015)

Approach 6.2: Diversify existing systems with new combinations of varieties or breeds.

Along with diversification of crop varieties and livestock breeds themselves (see previous approach), it may also be useful to diversify systems to include new combinations of varieties or breeds. For example, a pasture system that includes a combination of both currently common and potentially future-adapted varieties and breeds can reduce the risk associated with one variety or breed performing poorly and provide time to gain experience with using new, future-adapted varieties and breeds. At the same time, there is risk in anticipating which combinations may be future-adapted, as climate variability can have a greater impact on production than the long-term trend.

Example Adaptation Tactics

Field and forage crops:

- Plant multi-species cover crop mixtures including species currently adapted to warmer or drier climates
- Integrate livestock into cropping enterprises to utilize aftermath grazing on crop residues and cover crop grazing (Derner et al 2015)

Animal agriculture:

- Integrate livestock into cropping enterprises to access additional forage, reduce feed costs, eliminate manure concentration areas, or improve overall farm efficiency
- Alter mix of grazing species (Anwar et al. 2012)
- Plant multi-species pasture mixtures including species currently adapted to warmer or drier climates

Integrated agricultural systems:

- Diversify and expand farm production to include a greater number of annual crops, perennial fruits or nuts, timber or other forest products, livestock, or other commodities (may or may not include agroforestry approaches)
- Use excess heat from methane digestion to provide heat for other enterprises associated with the livestock operation such as greenhouse plants or aquaculture production (25 by ’25)

Approach 6.3: Switch to commodities expected to be better suited to future conditions.

As climate conditions change, it may become necessary to switch to new plants, animals, or systems in order to maintain a viable farm under new conditions. This is not a new idea, and agricultural producers have a long history of changing practices in response to changing markets, technologies, and environmental conditions (Olmstead and Rhode 2011; Walthall et al. 2012). The degree of anticipated climate change, however, may require greater investment and experimentation of new plants, animals, and other commodities and at a much larger scale, and farms may need to change to different systems altogether. For agricultural producers to successfully shift to new commodities and systems, it will also be important that accompanying advances in technologies (e.g., alternative crops/livestock, decision-support tools, etc.) and markets be made as well (Walthall et al. 2012).

Example Adaptation Tactics

Cropping systems:

- Use new cultivars and new species that seem to match a changing climate (Ames and Dufour 2014)
- Shift to more water-efficient crops or cropping systems (Derner et al 2015)(Ames and Dufour 2014)
- Preserve genetic resources by relocating at-risk varieties to locations that are expected to provide future habitat or reserving seed for future use
- Shift crops to types that can be grown in a controlled environment, using hoop and high tunnel houses or greenhouses

Animal agriculture:

- Switch to alternative livestock breeds, class, or species, especially those with a higher heat, drought, and parasite tolerance (Derner et al 2015)
- Preserve genetic resources by relocating at-risk breeds to locations that are expected to provide future habitat or reserving seed for future use

Strategy 7: Alter agricultural systems or lands to new climate conditions.

Beyond deliberate changes in farm commodities and practices, there may be a need for wholesale change within agricultural systems due to the degree of change observed in a particular place. While agriculture has been able to largely adapt to recent changes in climate, substantial pressures from climate change and associated socioeconomic changes will create substantial challenges in coming decades (Hatfield et al. 2014). This strategy touches on actions to respond to severely changed conditions in a way that anticipates continued change and uncertainty in the future.

Approach 7.1: Minimize potential impacts following disturbance.

Potential increases in the frequency, intensity, and extent of large and severe disturbances, such as extreme precipitation or storm events, may disrupt vegetation and result in the loss of plant cover, productivity, or function. Changing conditions are expected to increase the risk of crop losses and failures. Prompt remediation and revegetation of sites following disturbance helps to reduce soil loss and erosion, maintain water quality, and discourage weedy species in the newly exposed areas.

Because many of the best opportunities for addressing disturbance-related impacts are likely to occur immediately after the disturbance event, having a suite of pre-planned options in place may facilitate an earlier and more flexible response. Where a particular event exceeds the resilience of a particular location or system and a return to previous conditions is no longer feasible, this approach complements Approach 7.2 (Realign severely altered systems toward future conditions) that follows.

Example Adaptation Tactics

Cropping systems:

- Seed short-term cover crops to protect and stabilize soils
- Remove or prevent establishment of invasive plants and other competitors following disturbance through the use of herbicides, tilling, or other control measures
- Convert severely impacted areas or areas at risk of repeat disturbances to plants that are less susceptible to disturbance, such as other crops, perennial forage, or native plantings.
- Reshape damaged areas prior to replanting

Associated agriculture lands:

- Ensure that emergency response actions do not do more damage to resources than the emergency itself

Approach 7.2: Realign severely altered systems toward future conditions.

Agricultural lands may face significant impacts because of climate change-related disruptions, including drought, severe weather events, and invasive species (Hatfield et al. 2014; Walthall et al. 2012). Some systems may experience significant disruption and decline such that even intensive management may be insufficient to maintain desired conditions or achieve intended goals (Millar et al. 2007). This approach fundamentally allows producers to “reset” their management to select new commodities or production systems that are expected to be better matched to current and anticipated conditions.

Example Adaptation Tactics

All agricultural systems:

- Convert affected areas to plants or animal commodities that are expected to be suitable to future conditions
- Shift agricultural production spatially, matching commodities to areas with better climate conditions or water availability

Approach 7.3: Alter lands in agricultural production.
Ultimately, lands may become more or less suitable for agricultural production in the future. Some lands may become unsuitable for agriculture, particularly in areas that become substantially hotter or drier, necessitating a change to other land uses (Rosenzweig et al. 2014). At the same time, warmer conditions may increase the viability of agricultural commodities in other areas, particularly farther north, and allow for expanded production (Rosenzweig et al. 2014). While many of these changes will occur at large spatial scales and be affected by national and global policies, individual producers and landowners will make the decisions about site-level production (Smit et al. 1999; Neil Adger et al. 2005).

Example Adaptation Tactics

All agricultural systems:

- Shift agricultural production spatially, matching commodities to areas with better climate conditions or water availability
- Convert agricultural lands to new commodities based upon altered climatic conditions, such as converting row crops to perennial forage where water availability decreases
- Remove lands from agricultural production
- Add lands to agricultural production, recognizing the potential of negative impacts on natural ecosystems or environmental benefits.

Strategy 8:
Alter infrastructure to match new and expected conditions.

Altering infrastructure is a strategy that supports the entire menu of adaptation responses. Because infrastructure generally has a high cost and long life span relative to other farm practices and activities, there is a greater need to consider the long-term implications of these investments. Changes and upgrades in farm infrastructure represent a specific opportunity for agricultural producers to consider deliberately expected future climate conditions, risks, and opportunities that could affect farm productivity and sustainability. Changes in infrastructure can be used to resist the effects of climate change and maintain current practices in place for a longer period of time, such as through the use of increased irrigation to offset reductions in precipitation. On the other end of the spectrum, altering infrastructure may facilitate a transition to entirely new systems, such as through the purchase of new facilities or equipment necessary for the production of a new, future-adapted commodity.

Approach 8.1: Expand or improve water systems to match water demand and supply.
Increasing temperatures will likely increase water demand through enhanced evaporation from soils and transpiration from plants. Agriculture in the Midwest is likely to be affected where increased temperatures are not offset by a corresponding increase in precipitation, causing moisture stress, dry spells, and drought (Hatfield et al. 2014). In addition to practices to increase soil water retention and adjust plant crops or animal breeds to match drier conditions (described earlier), it may be necessary to expand infrastructure to increase the amount of water available to plants and animals. Because of the cost associated with many of these practices, efforts to increase the extent, capacity, or efficiency of water systems may be best suited to high-value or less water-intensive commodities (Wolfe et al. 2011; Blanc and Reilly 2015).

Example Adaptation Tactics

Animal agriculture:

- Construct ponds and swales, dig wells, collect rainwater {Ames, 2014 #38}

Cropping systems:

- Increase irrigation capacity or land under irrigation, particularly for high-value crops (Wolfe et al. 2011, Walthall et al, 2012, Blanc and Reilly 2015)
- Improve irrigation efficiency with latest technology such as micro or drip irrigation or using subsurface irrigation or irrigation with gray or reclaimed water (Ames and Dufour 2014, Derner et al. 2015)
- Expand water storage, irrigation, and drainage using deeper wells, cisterns, farm ponds, and more efficient irrigation (Ames and Dufour 2014, Tobin et al. 2015)
- Construct ponds and swales, dig wells, collect rainwater to maintain water on the landscape (Ames and Dufour 2014)
- Install or enhance drainage systems (Morton et al. 2015)
- Dig deeper wells and install more cisterns, farm ponds, and more efficient irrigation to accommodate hydrologic change (Ames and Dufour 2014)

Approach 8.2: Use structures to increase environmental control for crops.
Excess precipitation, heat stress, and other changes in climate pose substantial challenges for crops. Previously, Approach 3.2 (Manage crops to cope with warmer and drier conditions) describes actions to manage current crop systems for reduced heat stress by modifying plant density, soil moisture availability, or plant genetics or variety. This approach focuses on changes to infrastructure that reduce the effects of altered climate on crops, including heat stress and extreme weather events. In some instances, technological solutions may help transition to a new, future-adapted commodity in anticipation of future climate changes; for example, hoop or high tunnel houses may create warmer conditions at northern sites for crops that currently grow in southern locations but which may grow locally without protection in the future.

Example Adaptation Tactics

Cropping systems:

- Move crops into a controlled environment, such as hoop and high tunnel houses or greenhouses (Tobin et al. 2015)
- Enhance energy efficiency in greenhouses to reduce heat loads and heat stress (Tobin et al. 2015)
- Use technologies to protect orchards from frost, such as sprinklers, heaters, and wind machines, to allow for more cold-sensitive varieties to be grown

Approach 8.3: Improve or develop structures to reduce animal heat stress.
Heat stress poses substantial challenges for animal agriculture. Approach 3.3 (Manage livestock to cope with warmer and drier conditions) described earlier outlined actions to manage current livestock systems for reduced heat stress by modifying stocking density, forage availability and type, and animal genetics or breed. This approach focuses on changes to infrastructure that reduce heat stress on animals.

Example Adaptation Tactics

Animal agriculture:

- Build new barns with adequate cooling capacity for future heat loads (Wolfe et al. 2015)
- Improve climate control in facilities using fans, misters, soakers, and other features (25 by ’25)
- Enhance energy efficiency in facilities using light-emitting diode (LED) lights and other features to reduce additional heat sources
- Design and implement new housing for animal agriculture with consideration for extreme weather events and future climate

Approach 8.4: Match infrastructure and equipment to new and expected conditions.
Beyond water conveyance structures, irrigation, and watering systems, alter other farm infrastructure to operate under new and expected conditions or to match other changes in management practices. Tactics under this approach may vary widely depending upon the farm operation, and could include adding new machinery to implement new practices or grow new commodities, or upgrading buildings and facilities to handle increased snow or wind loads.

Example Adaptation Tactics

All agricultural systems:

- Update farm machinery to match new and future farm practices and commodities
- Consider precision nutrient and pesticide application systems
- Upgrade to more energy efficient equipment or integrate on-farm renewable energy generation (e.g., manure and biomass conversion and combustion, wind, solar) enterprises
- Upgrade building facilities to handle expected increased snow or wind loads

Conservation cover improves soil and water functioning in an orchard.

CHAPTER 4:
Adaptation Workbook

Climate change is becoming an increasingly important consideration in land management planning and decisionmaking at a variety of spatial scales. The **Adaptation Workbook** outlines a flexible five-step process to help agricultural producers, service providers, or educators consider the potential impacts of increasing climate variability and change and identify actions that facilitate adaptation to changing conditions (Box 4.1).

The process of adapting to climate change begins with defining current goals and objectives for agricultural production, profitability, and natural resource stewardship in a particular location (Figure 4.1). The next step assesses potential climate change impacts to the region and incorporates them as an additional consideration "filter" through which to evaluate critically the goals and objectives. Once appropriate adaptation actions are identified, monitoring and evaluation is used to determine if expected outcomes are being achieved. This flexible process draws upon locally relevant information resources about anticipated climate change impacts, such as the national, regional, and State-level assessments as well as the **Adaptation Strategies and Approaches** described in Chapter 3.

Figure 4.1. Use the process of adapting to climate change to incorporate considerations into long-range and annual operation plans. Climate change-related informational resources and tools support the adaptation decisionmaking process. Adapted from Janowiak et al. (2014).

Box 4.1: Using the Adaptation Workbook

The Adaptation Workbook can help producers, service providers, and educators:

- Incorporate climate change considerations into long-range and annual operations planning and decisionmaking based on experience and expertise.
- Incorporate adaptation responses into revision or development of farm or project plans.
- Discuss climate change-related topics with project stakeholders.
- Continuously learn by doing and evaluating incremental changes that inform longer term strategies.
- Document considerations, decisions, and outcomes regarding climate change adaptation.

The Adaptation Workbook does not:

- Make recommendations or set criteria for making decisions.
- Provide specifications for implementing response actions.
- Establish a plan for implementation of the selected actions and monitoring efforts.

Getting Prepared:

- Before you begin, it will be helpful to review information about your farm or project area such as business or project plans, conservation plans, maps, and production and land management records from the last 5 years.
- It may take several hours to move through all the steps of the **Adaptation Workbook**, especially if you are just getting familiar with climate change information or if you have a complex operation.
- Print the blank worksheets provided at the end of this workbook for use alongside step-by-step instructions. You may want to use this workbook in facilitated small group settings or with an advisor to help identify and access additional resources needed to complete the worksheets.

Step-by-Step Instructions:

- Follow the five steps in order, although you can always go back to add or clarify earlier responses. Review workbook items and key questions for each step and then fill out each item in the worksheet. Some steps have additional details.
- Where applicable, see additional guidance under the heading ***Slow Down To Consider . . . .***
- When you have completed all the steps in the **Adaptation Workbook**, you will have a set of worksheets to combine with or add to your existing plans for the farm or project.
- You can work toward implementing adjustments or transformations through time, either on your own or with your trusted financial, production, and conservation advisors and service providers.

Vegetable grower getting help from a trusted advisor.

Step 1:
DEFINE management goals and objectives.

About This Step

This step records fundamental information about the farm or project area. Because it serves as a starting point for the subsequent steps, it is very important to define clearly the current farm management goals and objectives. This information may already be available as part of management plan or other planning document. If you will be going through the workbook as part of a group, it may be most efficient for one or two people to compile information for this step in advance of any group discussions.

Key Questions:

- Where are you located?
- What do you care about?

Description of Workbook Items

Farm or Project Area – Name of the farm or the project area. Projects can be individual farms and properties or a group of multiple lands in a geographical area such as a watershed, landscape feature, or community.

Location – Describe the geographic location of the farm or project area (e.g., county, township, or watershed).

Management Unit – List any management units (e.g., properties, fields, or groups of fields) that are relevant to your farm or project area.

Management Goals – List the management goals for the farm or project area (Box 4.2). These may include short and long-term goals for products or services provided from the land, business profitability, and or stewardship of natural resources.

Management Objectives – List any management objectives for the farm or project area (Box 4.2). These will explain how to achieve management goals. There may be multiple objectives for a single management goal.

Timeframes – List approximate periods for achieving farm or project goals and objectives. As a default, identify the point in both the short term (within the next 5 years) and the long term (5 to 20 or more years) that you can use to consider and monitor how things may change over time.

Climate variability and change are likely to adversely impact dairy livestock and crop production and may also provide opportunities.

Box 4.2: Goals and Objectives

Management Goals
Management goals are broad, general statements, usually not quantifiable, that express a desired state or outcome to achieve. They are often not attainable in the short term and provide the context for more specific objectives.

Management Objectives
Management objectives define specific, measurable, achievable, results-oriented, and time bound actions needed to achieve desired outcomes expressed by the broad management goals. Objectives commonly include information on resources or methods to use, and they form the basis for further planning to define the precise steps to take.

Table 5.3—Examples of a management goal and its corresponding management objectives.

Management Goal	Management Objectives
Maintain and improve farm production and revenue	• Monitor herd health through annual veterinary check ups • Expand herd from 800 to 950 animals over next 5 years
Protect water quality and quantity of water in local streams, groundwater sources, and other water bodies.	• Reduce annual nitrogen load in runoff by 10 percent • Prevent annual soil erosion rates from exceeding tolerable loss on all cropland • Convert all highly erodible lands to perennial crops within 5 years • Improve water infiltration and soil moisture retention by increasing soil organic matter to 5 percent within 10 years.
Mitigate greenhouse gases	• Increase carbon sequestration in plants and soil organic matter by fertilizing perennial crops annually • Reduce annual nitrogen fertilizer use and associated nitrous oxide emissions by avoiding applications on wet soils and applying them as close to the period of crop uptake as possible

Step 2:
ASSESS site-specific climate change impacts and vulnerabilities.

About This Step

Climate change will have a wide variety of impacts, both potentially negative and positive, on agricultural production. For this reason, it is critical to not only think about the general (e.g., regional or statewide) effects and potential impacts of a changing climate, but also to consider how your farm and agricultural production system may be uniquely affected.

Key Question:

- How might the area be uniquely affected by climate change?

In this step, you will consider broad-scale scientific information about the expected effects of climate change in your region using vulnerability assessments or other published sources. After identifying these relatively general impacts, you will use your expertise and experience to evaluate how your farm or project area may be affected by climate change. Because there is a great deal of variation among different locations, your understanding of specific local conditions will help you identify the more relevant response actions in later steps. Some of the things you will want to consider include soils, topography, past management, current infrastructure and equipment, current access to technology or markets, or other factors that increase or reduce the ability of the farm or project area to cope with change. Importantly, this step focuses on the effects of climate change on the farm or project area, while Step 3 considers how management objectives may be affected.

Description of Workbook Items

Management Unit – Insert the management unit that you identified in Step 1.

Regional Climate Change Impacts and Vulnerabilities– Begin by creating a list of relevant climate change impacts and vulnerabilities for the region or area that you are working in. You may also want to identify the source of this information. Some of it may be relevant to the entire project area, while other information may only apply to specific locations on the farm as identified in Step 1.

Many resources on climate change impacts and vulnerabilities exist, such as reports and peer-reviewed papers on climate change. Several regions and States have vulnerability assessments that provide this information for an entire area, as well as by sector.

Climate Change Impacts and Vulnerabilities for the Farm or Project area– As you consider the regional impacts and vulnerabilities (above), draw upon your experience and knowledge to define the specific ways that your farm or project area may be affected by a changing climate (Box 4.3). For example, a field may have greater vulnerability to anticipated increases in the frequency and intensity of storm events because of steeper slopes or less vegetative cover.

Box 4.3: Climate Change and Your Farm or Project Area

Most of the available information on the potential effects of climate change has likely been developed for spatial scales that are larger than your farm or project area. It is important to consider not only this broad-scale information, but also how your particular location may be uniquely susceptible to these effects. Factors that may influence the risk to a specific location include:

- Landscape pattern, such as topographic position, slope, or aspect
- Soil characteristics, including texture, nutrient levels, and organic matter content
- Management history
- Current management, land cover, or land use
- Presence of or susceptibility to pests, disease, or nonnative species that may become more problematic under future climate conditions.

Step 3:
EVALUATE management objectives given projected impacts and vulnerabilities.

About This Step

In earlier steps, you defined management goals and objectives for your farm or project area (Step 1) and considered climate change impacts and vulnerabilities for this area (Step 2). In this step, you will identify management challenges and opportunities associated with climate change. You will also evaluate the feasibility of meeting your management objectives under current management and consider altering or refining them to account better for changes in climate.

Key Questions:

- What management challenges or opportunities does climate change present?
- Can current management goals and objectives be met? Or do they need to change?
- What other considerations affect your decision?

Note: It is inevitable that discussion will jump ahead at times to identifying approaches or developing tactics that can help agriculture cope with the anticipated impacts; rather than lose these ideas or skip critical steps in the process, be sure to record any ideas that will be useful in later steps.

Description of Workbook Items

Management Unit – Insert the management unit(s) that you identified in Step 1.

Management Objectives – Insert the management objectives that you identified in Step 1.

Challenges To Meeting Management Objective With Climate Change – List ways in which climate change impacts and associated site-specific vulnerabilities may make it more difficult to achieve each management objective. For example, warmer temperatures and drier conditions may limit the ability to bring a specific product to market economically. Focus on concerns related to on-farm challenges, since other considerations (e.g., insurance, government programs) will be included later in this step.

Opportunities for Meeting Management Objective With Climate Change – List ways in which climate change impacts and associated vulnerabilities may make it easier to achieve each management objective or create new management opportunities. For example, longer growing seasons may increase the opportunity for more production. Focus on farm challenges, since other considerations (e.g., insurance, government programs) will be included later in this step.

Feasibility of Meeting Management Objective, Under Current Management – Consider how the challenges and opportunities that you have identified may affect the feasibility of meeting objectives using actions within the current management trajectory (i.e., without intentional climate change adaptation). Feasibility can be determined for individual or multiple timeframes (e.g., short-term versus long-term).

- **High –** Existing management options can be used to overcome the challenges for meeting management objectives under climate change. Opportunities likely outweigh challenges.
- **Moderate –** Some challenges to meeting management objectives under climate change have been identified, but these can likely be overcome using existing management options. Additional resources or enhanced efforts may be necessary to counteract key challenges or promote new opportunities.
- **Low –** Existing management options may not be sufficient to overcome challenges to meeting management objectives under climate change. Additional resources or enhanced efforts will be necessary to counteract key challenges or promote new opportunities.

Other Considerations – List any other considerations that you may have, such as social, financial, administrative, or other factors that are part of your decision to pursue or change your management objectives but that may not be within the purview of farm-level decisionmaking.

Slow Down To Consider...

Climate change may make some management goals and objectives more difficult to achieve in the future, and there may be situations in which they need to be altered or refined to better account for anticipated climate change impacts. After completing Step 3, you should have a much better idea about whether your management objectives are feasible, given the current management options that are available to you. You have also identified social, economic, or other considerations that may affect your decision to pursue certain management objectives.

Are you going to continue with the management objectives you have identified?

If you have high feasibility of meeting your management objectives and these objectives are still sound, given projected climate change impacts, you can proceed to Step 4 to explore adaptation actions.

If some or all of your management objectives have moderate or low feasibility, or if they no longer seem sensible under climate change (e.g., managing a crop that may not be viable in the long term), you may reconsider your management objectives or your broader management goals. You can record any potential issues or changes in the “Other Considerations” section of Step 3 or return to Step 1 to alter your management goals and objectives. Use the information that you have gathered up to this point to create goals and objectives that are more likely to succeed, given projected impacts from climate change.

Step 4:
IDENTIFY adaptation approaches and tactics for implementation.

About This Step

In order to address the challenges or opportunities brought about by climate change, it may be necessary to adjust existing practices, try out completely new ones, or start a new system. The **Adaptation Workbook** helps you identify and evaluate specific actions that can help prepare for changing conditions given the challenges and opportunities that were identified in Step 3. In doing this you will generate a custom set of adaptation *tactics*—prescriptive actions specifically designed for your farm or project area and your unique management objectives.

Key Question:

- What actions can enhance the ability of your property or project area to adapt to anticipated changes and meet management goals?

The step also helps you create a clear rationale for your suggested tactics by connecting them to broader adaptation ideas. Chapter 3 of this publication contains a menu of **Adaptation Strategies and Approaches** (Box 3.2) for agriculture. As you brainstorm and evaluate ideas for adaptation tactics, you will also link these specific ideas to the list of more general adaptation strategies and approaches. These links will provide important context and rationale to justify your adaptation tactics. If you need help brainstorming specific adaptation tactics, you can use the **Adaptation Strategies and Approaches** as a springboard to develop specific tactics that can help achieve your management objectives.

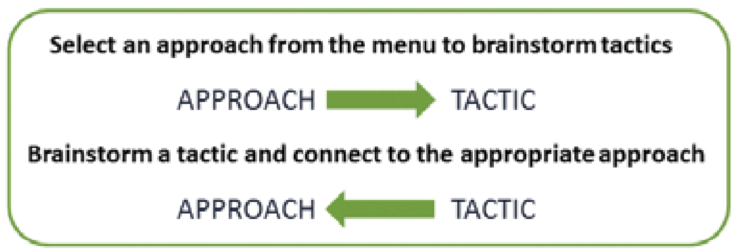
Description of Workbook Items

Management Unit – Insert the management unit(s) that you identified in Step 1.

Adaptation Actions

- **Adaptation Strategies and Approaches –** Review the Adaptation Strategies and Approaches (Chapter 3) and select any strategies and approaches that you think may be applicable. Also, include any additional approaches that you devise.
- **Adaptation Tactics –** Describe specific actions that you can take on your farm or project area using your own or your advisor's experience and expertise.

Because adaptation strategies and approaches provide long-range context for specific tactics that will be implemented, we encourage you to identify both; however, you may find it easier to list tactics first and then go back to identify the corresponding strategies and approaches.



This sequence is flexible. Start with Approaches or Tactics, but be sure to relate them to each other.

Timeframe(s) – List the approximate timeframe(s) in which the new tactics would be implemented. The nature of the action can help determine an appropriate timeframe. Some actions may occur in the short term (i.e., next 5 years), while others may not occur for several decades or will occur only in certain situations (such as after a large storm event).

Benefits – For each tactic, list any benefits associated with using this tactic. For example, note if a tactic addresses your biggest challenge, addresses multiple challenges, or has a side benefit, such as improving overall ecosystem health.

Drawbacks and Barriers – For each tactic, list any drawbacks that may arise, such as negative ecosystem impacts, or any barriers to implementing the tactic, including legal, financial, infrastructural, social, or physical barriers.

Effectiveness and Feasibility of Tactic – An adaptation tactic is practicable if it is both effective (it will meet the desired intent) and feasible (it is capable of being implemented). Both of these characteristics increase the likelihood of success. Consider the benefits, drawbacks, and barriers associated with each tactic in order to determine the practicability of meeting your management goals and objectives using that tactic.

- **High –** The tactic is expected to be both effective and feasible. Benefits of the tactic clearly outweigh drawbacks and barriers.
- **Moderate –** There are drawbacks or barriers that could reduce the effectiveness or feasibility of the tactic. Some drawbacks or barriers may be able to be overcome through the use of other adaptation tactics or management actions.
- **Low –** The tactic does not appear to be effective or feasible. The drawbacks and barriers are insurmountable or the benefits are too small relative to the required effort. The tactic may need adjustment to be made more effective or feasible.

Recommend Tactic? – For service providers and educators, consider the timeframe, benefits, drawbacks, barriers, and practicability for each tactic and select the tactics that you recommend for consideration in future management decisions. Identify tactics that overcome or avoid challenges, have high practicability, or have major benefits. For each tactic, determine whether you would recommend it for consideration in future management decisions:

- **Yes –** This tactic will likely be helpful in overcoming management challenges from climate change and meeting management objectives, and it should be considered in future management decisions. If needed, note any barriers that need to be overcome to use this tactic.
- **No –** This tactic is not helpful, and it is not recommended for current consideration in future management activities.

As you identify recommended tactics, consider how they work together as a set of actions. The goal is to identify a set of actions that are complementary and help to overcome the barriers identified in the previous step in order to achieve your management goals and objectives.

Step 5:
MONITOR and evaluate effectiveness of implemented actions.

About This Step

Monitoring is critical for understanding what changes are occurring as a result of climate change as well as whether selected actions were effective in meeting management goals and adapting your farm to future conditions. This step helps to identify metrics that will be used to monitor **whether management goals are achieved in the future and to determine whether the recommended management tactics were effective**. The outcome of this step is a realistic and feasible monitoring scheme that can be used to help determine whether management should be altered in the future to account for new information and observations.

Key Questions:

- How will you know if the selected actions were effective?
- What can we learn from these actions to inform future management?

Consider what existing monitoring information is available (such as farm records) and if it needs to be modified to better monitor the results of your adaptation actions. Also, consider what new monitoring items may be needed to evaluate whether you have met your management goals.

Description of Workbook Items

Management Unit– Insert the management unit(s) that you identified in Step 1.

Adaptation Monitoring Variable – Identify monitoring items that will be used to evaluate whether you have achieved your management objectives and goals, or whether you have achieved a milestone that indicates that you are working toward your goal. When possible, select monitoring items that will also help you to understand whether the adaptation tactics recommended in the previous step were effective in working toward your management goals under climate change.

Criteria for Evaluation – Identify a value or threshold that is meaningful for this monitoring item.

Monitoring Implementation – Describe how and when this information will be gathered.

Next Steps

By using this **Adaptation Workbook**, you have considered the effects of climate change on your farm or project area. You have also identified management tactics and monitoring efforts to help you meet your management objectives under a changing climate. Now that you have completed this step toward improving the ability of your farm or project area to adapt to the anticipated effects of climate change, you can work to integrate the information from the workbook, especially Step 4 and Step 5, into existing management plans and decisionmaking processes.

As you work toward this integration, it is important to keep in mind that the tactics you developed by completing the **Adaptation Workbook** have been recommended for further consideration (Step 4). Taking this step does not necessarily mean, however, that the tactics must be implemented or that the recommendations must supersede other considerations. The workbook is designed to lead you through a process for considering climate change, and it is up to you and your organization to determine the ways in which you will use the information and ideas you have developed.

Finally, the workbook is designed as part of an adaptive management process, which, by definition, needs to be able to incorporate new information as it becomes available. When developing a plan to implement your adaptation tactics and then monitor the results, also make plans to revisit this workbook as often as necessary to evaluate whether any changes are needed to your management strategy. Consult with experts whenever possible to gather new information and further refine your management decisions. As new information becomes available through scientific research, monitoring activities, or other avenues, use that information to consider how it may change your expectations regarding future conditions and whether it is appropriate to adjust your management or monitoring to help the systems adapt to a changing climate.

CHAPTER 5:
Adaptation Workbook Examples

The purpose of this publication is to assist agricultural producers with integrating climate change considerations into their plans and activities rather than providing specific recommendations. This chapter illustrates how the **Adaptation Strategies and Approaches** (Chapter 3) and the **Adaptation Workbook** (Chapter 4) can be used together to translate broad-scale climate change information into specific actions to adapt to changing conditions while meeting goals for productivity, profitability, and stewardship. Examples of real-world farms in the Midwest and Northeast regions of the United States. describe some of the diverse ways in which producers adapt to climate change.

Dryland Farming in Nebraska

Step 1:
Define management goals and objectives.

The five-step adaptation workbook process (Chapter 4) was tested for an agricultural setting using a portion of a 160-acre farm outside the town of Lawrence, in south-central Nebraska. The farm is owned by Mike Kucera, agronomist with the USDA Natural Resources Conservation Service. Kucera and representatives from USDA's Northeast, Midwest, and Northern Forest Climate Hubs worked together to evaluate the process and consider how climate change might affect the activities occurring on the farm over the next several decades and beyond.

Figure 5.1. Left: Location of the Kucera farm in Nuckolls County, Nebraska. Right: Aerial photo of the Kucera farm with outlined soil types. Images courtesy of Mike Kucera.

Mike Kucera has owned the farm for 25 years, implementing a wide variety of conservation activities. The overall goals for the Kucera Farm are to (1) maintain agricultural productivity, and (2) protect wildlife habitat (Table 5.1). The adaptation analysis focused on the 61 acres of cropland on the farm, which has been in continuous no-till (no cultivation) for the past 25 years. The farm uses dryland management techniques because the geology of the aquifer under the farm is unsuitable to irrigation development, a common practice across other parts of Nebraska. The cropland is currently in continuous no-till with a crop rotation of corn, soybean, and wheat (1 year each). Some of the cropland is enrolled in the Conservation Reserve Program, which includes small areas of grassed waterways, quail buffers, and about 13 acres of restored prairie. Additionally, another family member utilizes 90 acres of pasture for grazing 18 beef cow-calf pairs in a four-pasture rotational grazing system, for which the Adaptation Workbook was not used.

Table 5.1. Farm management goals and objectives for the Kucera Farm.

Farm or Project Area:	Kucera Farm		
Location:	~2.5 miles northeast of Lawrence, Nebraska		
Management Unit	**Management Goals**	**Management Objectives**	**Timeframes**
Entire Property	Maintain productivity of agricultural systems (yields) Wildlife habitat (hunting, recreation)	Maintain diverse land use including pasture, cropland, and Conservation Reserve Program	
Cropland (61 ac) Continuous no-till corn-soybean-wheat (1/1/1) Includes CRP lands: grassed waterways, quail buffers, prairie restoration	Conserve soil moisture by reducing evaporation and increasing infiltration, especially from high-intensity rainfall events Improve soil health	Maintain or even increase crop yields Utilize a residue and cropping management system that maximizes ground cover to reduce soil temperature during droughts Maintain high organic matter levels and soil life to protect and enhance soil structure for optimum water infiltration Maintain lands in CRP programs for conservation (if possible to reenroll)	Transition to a well-functioning management system took 7 years (improved soil structure, aggregate stability, and infiltration); Future soil improvements will be gradual and may take 10 years or more.
Pasture (90 ac) Four-pasture rotation – beef cow/calf herd	Maintain productivity of cows and calves Maintain and increase plant vigor of pasture grasses	Maintain productive cow herd while maintaining good vegetation Reduce negative impacts to vegetation from hot/dry periods during the grazing season Adjust the size of foraging herd to match vegetation conditions based on moisture availability	Annually

Step 2:
Assess site-specific climate change impacts and vulnerabilities.

Vulnerability assessments provide useful information about the anticipated effects of climate change for a region. A vulnerability assessment for Nebraska (Bathke et al. 2014) was used to identify potential climate change effects across the region (Table 5.2). This information was combined with knowledge of the local landscape, including actual impacts from extreme heat and precipitation in recent years, to identify attributes of the property that would make it more or less vulnerable to climate change than the region as a whole.

Across the Northern Plains, climate change is expected to have substantial effects on agricultural production as a result of longer, hotter growing seasons, increased drought, and extreme weather events (Derner et al. 2015). Evidence of enhanced climate variability is already visible in increased extreme weather events that have been seen across the region, such as the extreme drought of 2012 (Derner et al. 2015).

The projected impacts across Nebraska and the Northern Plains were largely applicable to the Kucera Farm (Table 5.2). At the same time, several factors associated with the local site conditions and past management history were identified that may reduce the vulnerability of the farm to climate change. Most notably, the practice of no-till farming and other conservation-oriented techniques to increase soil organic matter have greatly improved soil quality and made the site more resilient to hydrological extremes—both drought and extreme precipitation. Maintaining crop residues on the surface conserved moisture and reduced soil temperature during the severe drought of 2012 and during a dry spring and early summer in 2013. This system also paid dividends by reducing runoff, especially during an extreme 5-inch rain event in September 2012 and 4.5-inch rainfall event in June 2015 (Figure 5.2). Maximizing the amount of infiltration from these extreme events is crucial to capture rainfall in order to maintain yields when soil moisture is lacking later in the growing season. While these rainfall events had extensive runoff losses in the area, the adverse impacts were less on the Kucera farm because of increased infiltration due to the use of a continuous no-till management system.

Figure 5.2. Left: Corn planted into wheat stubble during the severe drought of 2012. Right: Evidence of an extreme precipitation event in September 2012. Photos courtesy of Mike Kucera.

Table 5.2. Site-specific climate change impacts and vulnerabilities for cropland on the Kucera Farm. Regional climate change impacts and vulnerabilities were derived from a statewide assessment of climate change impacts in Nebraska (Bathke et al. 2014).

Regional Climate Change Impacts and Vulnerabilities	Climate Change Impacts and Vulnerabilities for the Farm or Project Area
Warmer temperatures: Nebraska temperatures have warmed about 1°F since 1895 and are projected to increase another 4–5°F to 8–9°F by 2071–99. More extreme heat days & waves are also expected. **Longer/warmer growing seasons:** two more weeks by mid-century **Increased potential for drought:** due to higher temperature and increased temp variability **Altered precipitation:** Little change in winter/spring; Potential for drier summer **Increased extreme precipitation events** resulting in increased runoff **Reduced soil moisture:** Across NE projected to decrease from 1-5 percent to 5-15 percent by end of century due to warmer temperatures and altered precipitation	Warmer temperatures: Big impact in 2012. Warmer temperatures and reduced soil moisture killed cover crop; reduced yields. Cropland is most affected by changes in precipitation: • drought • extreme precipitation events **The Kucera property is less vulnerable to both drought and runoff than the local average** because of the no-till system and work done to date to improve soil quality and infiltration and reduce evaporation Crops are each affected differently based on their biology—influenced by annual rainfall patterns
Increased soil erosion potential: from extreme rainfall events	Site is relatively flat, but erosion can still occur on slightly sloping areas or on field borders where soil is compacted from traffic particularly during severe rain Field borders prone to erosion and runoff were placed in CRP CP33 quail buffer program
Altered streamflow: reduction in snowpack or altered precipitation may greatly reduce flows on Platte and Missouri rivers **Flood magnitude**: Expected to increase with extreme rain events	Not applicable here
Severe storms and tornadoes: high uncertainty about future change	Wind, heavy rains, and hail have the potential to impact crops. Hail damage severe enough to collect on crop insurance has only occurred once in the last 25 years.

Corn loss due to drought.

STEP 3:
Evaluate management objectives given projected impacts and vulnerabilities.

Climate change is expected to create numerous challenges to maintaining productivity of cropland on the Kucera Farm (Figure 5.3). These challenges generally reflected the greatest anticipated changes in climate, and the greatest challenges were associated with increasing variability in rainfall patterns (Table 5.3). Drier conditions due to warmer temperatures and/or reduced precipitation have direct negative effects on crop productivity and yields by reducing soil moisture. Additionally, lower plant productivity or enhanced decomposition can reduce the amount of residue cover increasing soil moisture loss and soil temperature while reducing long-term accumulation of soil organic matter. Conversely, extreme precipitation, wind, and hail events could cause increased crop damage. Moreover, the specific effects from either drought or extreme precipitation are impossible to predict in advance because the outcome will vary greatly depending upon the severity of the event, when during the year the event occurs, and the timing of the event relative to the 3-year crop rotation of corn-soybean-winter wheat.

Cropland at the Kucera Farm planted to switchgrass forage. Photo courtesy of Mike Kucera.

Table 5.3. Challenges, opportunities and feasibility of meeting current management objectives given projected impacts and risks for cropland on the Kucera Farm.

Management Objective (from Step #1)	Challenges To Meeting Objective With Climate Change	Opportunities For Meeting Objective With Climate Change	Feasibility Under Current Management	Other Considerations
Maintain or increase crop yields	Increasing variability of rainfall: probably too little or at the wrong time Very extreme rainfall could cause crop damage Increases in pests and diseases	More rainfall infiltration could increase groundwater recharge (as long as not too great) Utilize high carbon-nitrogen ratio cover crops following wheat harvest to increase the amount of residue cover during hot dry summer months	High	
Increase residue cover and soil organic matter in order to maximize soil moisture in order to maintain reasonable levels of productivity during drought periods	Warmer temps result in greater respiration, which could impair yields reducing the ability to increase OM Multi-year impacts: low productivity one year could impact next year (residue on surface affects yield)	Utilize a stripper header machine for small grain harvest that maximizes standing cover and residue retention, or utilize high-carbon cover crops following wheat harvest to capture snowfall, increase infiltration, and reduce soil moisture loss. Possibly utilize cool season cover crops due to warmer winters Utilize a controlled traffic system to reduce soil compaction by confining wheel traffic to the same rows.	Maintain: high Increase: more difficult	
Maintain and improve soil structure, aggregate stability and porosity in order to continue improving water infiltration	Increased number of earthworms can increase the decomposition of residue, leading to less ground cover, which exposes soils to hot weather, degradation, and reduced yields	Plant high-carbon cover crops following wheat harvest such as sorghum Sudangrass or millet, or use high-carbon crops such as corn, sorghum, or wheat in rotation to maximize residue cover and retention	Maintain: high Increase: a bit harder...	
Maintain lands in CRP programs for conservation and wildlife benefits (if possible to reenroll)	Eligibility for program funding or re-enrollment in CRP			Plan to re-enroll quail buffers in fiscal year 2016

Step 4:
Identify adaptation approaches and tactics for implementation.

Within the challenges and opportunities identified in Step 3, a number of potential adaptation actions were identified with the overarching intent to maintain crop productivity and soil organic matter over the long term, while also addressing the potential impacts from climate change (Table 5.4). Given the limited nature of this exercise, only a few potential adaptation tactics were evaluated fully; several other adaptation responses were identified but not evaluated. These tactics are associated with the list of Adaptation Strategies and Approaches (Chapter 3).

It is important to note that many of the practices currently being implemented on the farm increase resilience to climate change, even though climate change was not a factor in the decision to implement these actions. For example, long-term efforts to increase soil organic matter through crop rotation, no-till farming, residue retention, and other practices have increased the farm's resilience to both drought and extreme precipitation. This illustrates how existing soil and water conservation efforts can have important climate adaptation benefits. Another example is the use of varieties of flex-ear corn, which produce a second ear of corn and increase production in favorable conditions.

While many current practices increase the farm's resilience to climate change, particularly in the near term, several additional actions were developed to enhance the ability of the farm to cope with changing conditions. These ranged from "small tweaks" of current practices to major changes in crops and systems. One example of a small adjustment is to utilize varieties to better match the current year's rainfall and temperature or anticipated longer term climate changes. This is a relatively easy action to implement, although it can be hard to get seed later in the year. Additional adaptation actions were considered, some of which would be a more substantial departure, including:

- **Change plant population** – Adjust the density of plants to match water availability
- **Utilize controlled traffic patterns** – reduce soil compaction by confining it to the same row
- **Utilize a stripper header to leave taller wheat stubble** – maintain residue longer to reduce moisture losses and capture more infiltration and snow
- **Utilize high-carbon cover crops following wheat harvest** – to increase soil organic matter and residue retention
- **Diversify crops** – A bigger farm could reduce the risk of production losses by planting multiple crops with varying seasons of growth; it is not as practical on smaller farms in many cases.
- **Substitute crops** – As the climate changes, other crops or rotations might be suitable. For example, sorghum could replace corn in the rotation under warmer and drier conditions.
- **Irrigation –** Developing irrigation could provide more options than dryland farming, but it is not a viable option for the Kucera Farm given the local aquifer geology and landforms.
- **Utilize grain sorghum in rotation –** Sorghum is more drought tolerant and adapted to higher temperatures.
- **Utilize low-water-use crops –** Crops such as field peas or canola (not currently economically viable) could be used if precipitation is consistently lower. Examples of other crop rotations that could be adopted to replace the wheat-fallow system include: winter canola/wheat with continuous no-till (used in Oklahoma) and wheat/spring canola or wheat/field peas/millet (used in western Nebraska, the Dakotas, and eastern Montana).

Table 5.4. Adaptation approaches and tactics for implementation on cropland of Kucera Farm.

Adaptation Actions		Time-frames	Benefits	Drawbacks & Barriers	Effectiveness and Feasibility of Tactic	Recommend Tactic?
Approach	**Tactic**					
1.1: Maintain and improve soil health.	Use legume cover crops after wheat in years that are projected to have wetter conditions to retain soil moisture	Any	• Provides ground cover and forage for grazing animals • Improves soil food web • Can provide nitrogen • Increase soil organic matter • Improves soil properties	• Getting sufficient soil water for germination • Can draw water from subsequent crops • More cost—does it maintain/ improve productivity • Curl mites and green bridge for wheat-streak mosaic disease might get worse	Moderate-High	Yes
3.1: Adjust the timing or location of on-farm activities 6.2: Diversify existing systems with new combinations of varieties or breeds. 6.3: Switch to commodities expected to be better suited to future conditions.	Plant sorghum instead of corn during the spring when soil moisture is low	Under warmer and drier conditions	• Better adapted to higher temperatures • Responds well to late Aug. rainfall (if they come)	• Sorghum will use soil moisture during the late fall and will not die until the first frost, leaving less moisture for next year; might need to terminate with a burn-down herbicide	High	Yes
	Alternative rotations, such as winter canola and wheat (used in Oklahoma)	Under warmer and drier conditions	• Works in very dry locations	• Not currently economically viable		
6.1: Diversify crop or livestock species, varieties or breeds, or products.	Diversify crops	Any	• Would spread risk across multiple crops	• Not viable given the small size of this farm	Low	No
3.2: Manage crops to cope with hotter and drier conditions.	Switch to irrigated systems	Under warmer and drier conditions		• Not viable given aquifer geology	Low	No

Step 5:
Monitor and evaluate effectiveness of implemented actions.

As adaptation tactics are implemented, it will be critical to evaluate whether they had their intended effect and do in fact help meet farm objectives in a changing climate (Table 5.5). In many situations, the current system of recording farm activities and production can be used to provide information about the effectiveness of the adaptation actions. For example, as management changes, crop yields can be compared to past yields (10-year or longer timeframe) to see if they stay the same or increase. Likewise, compare on-farm crop yields to county or local averages to evaluate the performance of the farm relative to neighboring farms, particularly those with similar soils and management history. Also record and informally monitor management adjustments such as the severity or extent of soil erosion or runoff occurring after a high-intensity rainfall event (e.g., 2-inch) rain event.

Evaluate soil health to determine the effectiveness of adaptive management.

Table 5.5. Potential monitoring items to evaluate the effectiveness of implemented actions for cropland on the Kucera Farm.

Monitoring Item	Criteria for Evaluation	Monitoring Implementation
Crop productivity (bushels per acre per year)	• Similar or better yields over a 10-year period	Continue current recordkeeping
Runoff after heavy storms, such as the degree of erosion or runoff after a 2-inch or higher precipitation event	• Times erosion or runoff is observed per season • Severity or extent of erosion and runoff in susceptible locations • Gullies or ephemeral gully erosion	Need to record

Beef Grazing in Missouri

Step 1:
Define management goals and objectives.

Missouri has the second highest beef cattle population in the Nation, with 1.8 million head of cattle (USDA, National Agricultural Statistics Service 2016). This example describes a small, 100-acre beef farm operation located in the Ozarks region of Missouri. The operation includes a mix of grassland in hay and pasture used for beef production, cropland, and forest used for timber management, to provide supplemental income to a family with off-farm work (Table 5.6).

Step 2:
Assess site-specific climate change impacts and vulnerabilities.

Climate change and variability is expected to adversely affect beef production in Missouri and across the Ozarks although some positive effects are possible (Hatfield et al. 2015). Annual temperatures are projected to increase an additional 2 °F to 7 °F through the end of the century in the Missouri Ozarks region (Brandt et al. 2014). Increased temperatures will result in longer growing seasons but also a greater number of hot days and warm nights during summer. Precipitation patterns are also expected to change, with increased precipitation in winter and spring and potential declines in summer (Brandt et al. 2014).

Altered precipitation patterns will increase the potential for both extreme precipitation events and drought. There are few site-specific variables that make this farm more or less vulnerable to climate change relative to other farms in the same part of Missouri, except that bottomland areas may be susceptible to streambank erosion from extreme rain events.

Adaptive grazing reduces risks from warmer and drier conditions.

Table 5.6. Existing management goals and objectives for a small farm in the Ozarks region of Missouri.

Management Unit	Management Goals	Management Objectives	Timeframes
Beef production: pasture and livestock (35 acres)	Supplement family income Maintain land and bequeath to family Minimize labor requirements Maintain forest productivity Improve recreational opportunities in forest land Increase net revenue	Increase livestock weight gain through dietary improvement	Short
		Maintain reliability of forage supply	Short
		Increase efficiency of feeding	Short
Cropland: alfalfa or annual forage (10 acres)		Enhance soil resource on bottomland	Short to Long
		Enhance riparian management	Short to Long
Forest: timber and wildlife management (55 acres)		Harvest hardwoods for sustained income	Short
		Manage riparian areas in bottomlands	Long
		Manage forest for wildlife	Long

Step 3:
Evaluate management objectives given projected impacts and vulnerabilities.

Several management challenges and opportunities were identified as a result of anticipated changes in climate (Table 5.7). For example, more days with extreme heat and warmer nighttime temperatures could increase the heat stress on animals or on forage, or even create challenges with pollination of important forage plants. Warmer temperatures and changes in annual precipitation, especially potential decreases in available moisture during the growing season, have the potential to decrease forage quality and quantity. Some potential changes in climate, however, such as longer growing seasons and fewer cold days and nights, were identified as potentially beneficial for plant growth, calving, and winter feed efficiency. Management objectives related to the beef pasture, livestock, and cropland are rated as having low feasibility under current management because the potential positive impacts of climate change (e.g., longer growing seasons, ability to plant cover crops in cropland) are not likely to offset the negative impacts. The feasibility of managing forest health and productivity is rated as moderate because the impacts from reduced precipitation, drought, and pests are expected to be less than on annual crops. An additional consideration is limited time available for farming due to the family having full-time jobs away from the farm.

Step 4:
Identify adaptation approaches and develop tactics for implementation.

Several adaptation strategies, approaches, and tactics can help this farm respond to identified adverse climate change impacts and achieve its current goals as well as take advantage of potential opportunities (Table 5.8). Climate change considerations became another driver to better manage natural resources and improve the overall functioning of the agroecosystem. Adaptation tactics for forest management were identified using a list of adaptation strategies and approaches for forest ecosystems (Swanston and Janowiak 2012).

Table 5.7. Selected climate change-related management challenges and opportunities for a beef grazing operation in Missouri.

Management Unit	Management Objectives	Challenges To Meeting Management Objective With Climate Change	Opportunities For Meeting Management Objective With Climate Change	Feasibility of Objectives Under Current Management
Beef production: pasture and livestock (35 acres)	Increase livestock weight gain through dietary improvement	Heat stress and lack of moisture will reduce summer forage quality and yield Day and nighttime heat stress will decrease feed intake More pests may slow weight gain	Warmer winters could increase winter forage supply and feed efficiency	Low
	Maintain reliability of forage supply			Low
	Increase efficiency of feeding			Low
Cropland: alfalfa or annual forage (10 acres)	Enhance soil resource on bottomland	Streambank erosion and flooding may damage crops and decrease cropland extent	Opportunities to plant cover crops may increase	Low
	Enhance riparian management			Low
Forest: timber and wildlife management (55 acres)	Harvest hardwoods for sustained income	Drought could decrease growth rate, stress trees, and increase susceptibility to pests or fire. Intense storms could reduce quality Extreme precipitation and stream flow will increase risk of streambank erosion Drought could decrease mast production Pests may increase	Drier weather could increase timber harvest windows	Moderate
	Manage riparian areas in bottomlands			Moderate
	Manage forest for wildlife and hunting			Moderate

Table 5.8. Selected adaptation tactics identified for a beef grazing operation in Missouri.

Adaptation		Time-frames	Benefits	Drawbacks & Barriers	Effectiveness and Feasibility of Tactic
Approach	**Tactic**				
Management Unit: Pasture					
1.1: Maintain and improve soil health. 6.1: Diversify crop or livestock species, varieties or breeds, or products.	Interseed legumes in pasture. Use limestone to neutralize soils, optimize phosphorus and potassium applications	1-2 yrs.	Higher forage quantity and quality	Risk of seeding failure Cost of soil analysis and amendments	High
3.1: Adjust the timing or location of on-farm activities. 3.2: Manage crops to cope with warmer and drier conditions. 8.1: Expand or improve water systems to match water demand and supply.	Improve grazing system by increasing from 4 to 8 paddocks	1-2 yrs.	Increased forage availability, utilization, and quality	Expense of additional fence and water distribution	High
3.3: Manage livestock to cope with warmer and drier conditions. 8.1: Expand or improve water systems to match water demand and supply.	Water distribution to all paddocks	5-10 yrs.	Reduce winter hay needs and labor by extending grazing season (stockpiling)		High
6.1: Diversify crop or livestock species, varieties or breeds, or products. 6.2: Diversify existing systems with new combinations of varieties or breeds.	Establish warm season grass paddock	1-2 yrs.	Increased forage available under warm and dry conditions	Expense of establishment; initial yield drag during establishment	Medium
Management Unit: Cropland					
1.2: Protect water quality. 5.1: Maintain or restore natural ecosystems. 5.2: Promote biological diversity across the landscape.	Convert cropland to riparian buffer	3-5 yrs.	Improve stream quality; reduce streambank erosion; provide emergency forage source; reduce labor	Takes some land out of production	High
6.3: Switch to commodities expected to be better suited to future conditions. 7.3: Alter lands in agricultural production.	Convert cropland to perennial pasture	1-2 yrs.	Improve stream quality; reduce streambank erosion; provide emergency forage source reduce labor	Time to establish vegetation; cost for fence	High
Management Unit : Forestland					
Maintain or improve the ability of forests to resist pests and pathogens. Promote diverse age classes. Maintain and restore diversity of native tree species.	Get a forest management plan, follow the recommendations of a professional forester	5-10 yrs.	Increase income opportunity	Delayed income, labor required to thin timber	Medium
	Improve upland wildlife habitat through thinning or timber stand improvement	5-10 yrs.	Enhanced recreation opportunity from viewing or hunting wildlife	Time and expense associated with actions	Medium

Step 5:
Monitor and evaluate effectiveness of implemented actions.

Several monitoring items can help to determine if the adaptation actions actually implemented are effective at overcoming management challenges or taking advantage of opportunities. In the beef pasture, adaptation monitoring focuses on forage quality and production by recording the number of days of feeding livestock hay in the winter and the weight gain of calves. Better forage production and utilization should reduce the number of days of feeding hay in the winter, while better forage quality should increase the rate of weight gain. In areas designated as riparian buffers, monitoring of streambank erosion consists of comparing future locations of vegetation and soil loss or deposition with pins inserted in the streambank and marked on aerial photographs indicating the baseline location.

The risk of more erosion rises with an expected increase of extreme precipitation events.

Corn and Soybean Production in Iowa

Step 1:
Define management goals and objectives.

More than 26 million acres of farmland were in corn and soybean production in Iowa in 2009, serving as a mainstay of the State's economy (USDA, National Agricultural Statistics Service 2016). This example broadly illustrates how to integrate climate variability and change into the planning and activities of corn-soybean operations typical across Iowa and other Midwestern States (Table 5.9).

Step 2:
Assess site-specific climate change impacts and vulnerabilities.

Climate change and variability is likely to adversely affect crop operations in Iowa and across the Midwest, although some positive effects are possible (Hatfield et al. 2015). Increased temperatures will result in longer growing seasons but also a greater number of hot days and warm nights. Altered precipitation patterns will increase the potential for both extreme precipitation events and drought. This particular farm is likely to experience impacts similar to those projected to occur across the region, as no site-specific factors increase or reduce its vulnerability relative to other farms in the same part of Iowa.

Step 3:
Evaluate management objectives given projected impacts and vulnerabilities.

Identified challenges and opportunities reflect projected climate change impacts and vulnerabilities for this corn and soybean crop operation (Table 5.10). Several key management objectives have a low feasibility because substantial challenges expected from adverse climate change impacts are not likely to be offset by positive impacts (e.g., longer growing seasons, ability to plant cover crops in cropland).

Table 5.9. Management goals and objectives for a 320-acre farm near Ames, Iowa, focused on corn and soybean production.

Management Unit	Management Goals	Management Objectives	Timeframes
Cropland (320-acre farm)	Increase productivity	Increase corn and soybean yields	Short
	Increase profitability	Decrease nitrogen use Improve water use efficiency	Short
	Improve soil health	Use cover crops Increase soil organic matter from current levels (1-2%) to 4%	Short
	Decrease profit volatility	Reduce soil erosion Improve nitrogen use efficiency Improve water use efficiency	Short
	Decrease environmental footprint	Become carbon neutral Minimize nitrogen loss	Long

Table 5.10. Selected climate change-related management challenges and opportunities for a farm producing corn and soybeans in Iowa.

Management Objectives	Challenges To Meeting Management Objective With Climate Change	Opportunities For Meeting Management Objective With Climate Change	Feasibility of Objectives Under Current Management
Increase corn and soybean yields	Variable summer precipitation, excessive summer precipitation, extreme heat, and warm summer nights likely to reduce yields	Beneficial effect from carbon dioxide fertilization	Moderate
Decrease nitrogen use Improve water use efficiency	Variable spring and summer precipitation likely to leach nitrogen and slow crop growth.		Low
Use cover crops Increase soil organic matter	Extreme precipitation increasing risk of erosion and crop damage	Longer growing season for cover crops	High
Reduce soil erosion Improve nitrogen use efficiency Improve water use efficiency	Variability in summer precipitation will enhance nitrogen volatility	Excess rain could be captured in soil or reservoirs	Low
Become carbon neutral Minimize nitrogen loss	Increased pests will require more chemicals. Extreme precipitation increases risk of nitrogen loss	Carbon dioxide fertilization will increase carbon sequestration	Low

Step 4:
Identify adaptation approaches and develop tactics for implementation.

Several adaptation strategies, approaches, and tactics identified in the table below enable this corn and soybean-cropping system to respond to potential adverse climate change impacts and persist in achieving its current goals as well as take advantage of opportunities (Table 5.11). Climate change considerations became another driver to better manage natural resources and improve the overall functioning of the agroecosystem.

Step 5:
Monitor and evaluate effectiveness of implemented actions.

Several monitoring items were identified that could inform the producer about whether the implemented adaptation actions were effective in helping to overcome management challenges or take advantage of opportunities (Table 5.12).

Table 5.11. Selected adaptation tactics for a farm producing corn and soybeans in Iowa.

Adaptation		Time-frames	Benefits	Drawbacks & Barriers	Effectiveness and Feasibility of Tactic
Approach	Tactic				
1.1: Maintain and improve soil health.	Mixed cover crop	1 yr.	Increases soil health	Water availability	High
1.3: Match practices to water supply and demand. 4.1: Reduce peak flow, runoff velocity, and soil erosion.	Improve water use via cover crop and strip till	1 yr.	Reduce production volatility	Variable water supply	High
3.2: Manage crops to cope with warmer and drier conditions. 8.1: Expand or improve water systems to match water demand and supply.	Increase water storage with either increased soil water-holding capacity or farm reservoir	5 – 10 yr.	Reduce production volatility	Expensive	Low
6.3: Switch to commodities expected to be better suited to future conditions. 8.4: Match infrastructure and equipment to new and expected conditions.	Switch commodity, potentially to niche crop	As market opportunities emerge	Increase diversity; mitigate volatility	Market uncertainty, cost, new equipment	Low
1.1: Maintain and improve soil health.	Add manure	1-3 yr.	Improve soil; add nitrogen and phosphorus in short term; increase carbon in long term.	Affects 1.2	Moderate
1.1: Maintain and improve soil health.	Split application of nitrogen	1 year	Enhanced nutrient utilization		High
1.1: Maintain and improve soil health.	Incorporate biochar	1-5 yr.	Improve soil		Moderate

Table 5.12. Selected adaptation actions for a farm producing corn and soybeans in Iowa.

Adaptation Monitoring Variable	Criteria for Evaluation
Crop yields	Increase above statewide average
Protein content	Increase above current levels
Soil organic matter	Increase above current levels
Water runoff	Examine after heavy rain (Is erosion present?)
Nitrogen runoff	Reduce from current levels
Environmental footprint	Reach negative carbon balance

Confined Dairy in Pennsylvania

Step 1:
Define management goals and objectives.

In 2012, sales of milk from cows in the United States totaled $35.5 billion, over one-third of which was from five States in the region: Wisconsin, New York, Pennsylvania, Minnesota and Michigan (USDA, National Agricultural Statistics Service 2016). This example shows how a confined dairy animal feeding operation in the Ridge and Valley province of Pennsylvania could respond to the effects of actual or expected changes in climate (Table 5.13). The overall strategic objectives of the enterprise are to maintain profitability and the family farm legacy. In order to produce a steady supply of high-quality whole milk, farmstead facilities house a herd of 800 dairy cows, store feed, and handle wastes. Approximately 2,000 acres of crop fields produce corn for grain and silage as well as alfalfa grass for haylage and dry hay.

Step 2:
Assess site-specific climate change impacts and vulnerabilities.

Climate change and variability are likely to adversely affect dairy production in Pennsylvania and across the Northeast, although some positive impacts are also possible (Tobin et al. 2015). Most dairies in the region manage both livestock and crop production. Increased summer temperatures may cause more heat stress on dairy cattle. Earlier springs and warmer winters allow for greater proliferation and survivability of pathogens and parasites. Extreme precipitation increases the risk of gully erosion and waste runoff from overtopping storage facilities. More severe winter storms may impede feeding and waste removal activities, while more severe summer storms increase the risk of damage to structures and injured livestock. This particular dairy is typical of confinement operations, and impacts are not likely to be greater than at others in the region.

Dairy crop production in the region typically includes corn silage and alfalfa grass, both likely to experience adverse impacts as well as opportunities from climate change and variability. More hot summer days and warmer nights, declining soil moisture, and drought are likely. Winter and spring precipitation patterns may limit the number of days with suitable field conditions, while severe storms in late summer and fall may limit harvest conditions (Tobin et al. 2015). Wetter soils for longer periods are also more susceptible to compaction. Bare or poorly covered soil, fields with recent nutrient application, and water conveyance structures are sensitive to intense storms and excessive rain. Increasing risk from increased weed pressure, higher levels of insect pest populations overwintering or arriving earlier in the spring, and increased winter survival rates of diseases are also concerns in the region. A potential opportunity to grow more forage may exist due to expected higher annual average rainfall, milder winters, and longer growing seasons.

This particular dairy operates lands with site-specific conditions that may make it more vulnerable than other dairies operating in the region. Over half of the fields have a south facing exposure, making corn and alfalfa more vulnerable to extreme heat stress. Many fields in valley areas have poor soil structure while fields on the ridges have well-drained soils, both conditions that increase the risk of crop damage from drought. Fields on steep hillslopes and on soils with a silt loam texture are more vulnerable to increasingly intense rainstorms, while those in the valley next to the stream are more vulnerable to flood damage. However, the farm has a few fields with a north-facing exposure and better soil structure, which are able to absorb water and cope with extreme heat.

Table 5.13. Management goals and objectives for a confined dairy operation in the Ridge and Valley province of Pennsylvania.

Management Unit	Management Goals	Management Objectives	Timeframes
Farmstead: Livestock facilities Dairy facilities Waste management facilities	Maintain family net income and farm legacy Minimize energy costs Maintain herd health and milk productivity	Minimize overall expenses	Short- Long
		Prevent water leaks and unnecessary lighting and ventilation, minimize fuel use	Short
		Prevent stress in dairy herd	Short
Croplands: Corn for grain Corn for silage Alfalfa grass for hay and haylage	Maintain or improve crop productivity Comply with concentrated animal feeding operation (CAFO) regulations Maintain friendly neighbor relations and positive community image	Minimize erosion and prevent soil compaction from heavy equipment	Short- Long
		Apply nutrients not to exceed annual crop need and soil test recommendations. Follow nutrient management plan to prevent non-point source pollution.	Short

Step 3:
Evaluate management objectives given projected impacts and vulnerabilities.

An evaluation of the dairy's existing management objectives for the farmstead found a few challenges, but no opportunities presented by climate change. In general, most of the current management objectives for the livestock, dairy, and waste management facilities were rated as having a slightly declining feasibility. Negative impacts from climate change (e.g., incrementally increasing costs of ventilation, veterinary services, and repairing infrastructure) were not expected to be offset by any positive impacts but were also not substantial enough to prevent achievement of farm profitability goals. However, impacts from increased waste spills from overtopped storage facilities, (e.g., costs, poor community image, and regulator inspection hassles) do present substantial challenges especially to the farm's stewardship goals.

Additional climate change-related considerations for this farm are rising costs of purchased supplemental feed or fertilizers due to negative climate change-related impacts in the region where the purchased feed is produced or increased cost of utilities rising due to weather disruptions of electricity. At the same time, the farm may be able to take advantage of market opportunities if climate change impacts increase production costs in other places, such as a long-term drought in California, and the farm is able to sell its milk at a higher price.

When taken together, the adverse climate change impacts on this dairy farm are not significant enough to necessitate a change in long-range goals and objectives. Instead, an adjustment of management tactics to maintain the current farming system would be adequate. To increase the farm's adaptive capacity to prepare and recover from expected adverse impacts, management objectives for the crop fields are being refined to improve soil functioning, nutrient stewardship, and fuel use efficiency, while on the farmstead more transformative changes are needed to improve nutrient stewardship.

Step 4:
Identify adaptation approaches and develop tactics for implementation.

A review of the menu of adaptation strategies and approaches found a number of approaches that enable this dairy enterprise to respond to identified adverse climate change impacts and achieve the management objectives of improving soil functioning and nutrient stewardship, reducing fuel use, and reducing risks of adverse impacts from extreme weather. (Table 5.14). Climate change considerations became another driver to better manage natural resources and improve the overall functioning of the agroecosystem.

The most transformative change occurs at the farmstead where the waste storage facility can be covered to prevent accumulation of rainfall and the risk of spills. In support of the nutrient stewardship objective for crop fields, the manure collection and handling system can be improved to separate liquids from solids to increase pumping efficiency, reduce costs, and apply nutrient sources near the time of crop nutrient uptake in locations best suited to utilize the source. Liquid fractions with more available nitrogen can be surface applied to fields with higher infiltration rates, higher organic matter, and low risk for phosphorous transport, while solid fractions will be applied to fields low in organic matter to stimulate soil biology. Another co-benefit of solid-liquid separation is the use of manure solids for livestock bedding to offset expensive wood shavings. At this time, methane capture from the covered waste storage facility for electricity generation is not feasible.

Step 5:
Monitor and evaluate effectiveness of actions.

Monitoring activities and evaluation criteria were identified for this dairy to determine whether the adaptation tactics described above, if implemented, would be effective actions to overcome the challenges of a changing climate and meet the farm's long-range goals and objectives. On the farmstead, climate adaptation monitoring and evaluation criteria focus on maintaining the cover of the waste storage facility. A cover in proper condition eliminates the risk of waste runoff overtopping the facility during a rainstorm.

To monitor progress towards achieving new objectives and evaluate outcomes on crop fields, recordkeeping can be improved to include tracking of application rates and costs of fertilizer and soil amendments, the soil's infiltration capacity and organic matter percentages within fields, and gallons of fuel saved by pumping liquids compared to hauling slurries. To supplement data collected, the farm visually monitors storm water runoff at the edge of high-risk fields, taking photographic evidence during and shortly following severe weather. At the end of the installation of the waste storage facility cover and solid liquid separation system and other supporting practices, all costs and benefits will be evaluated compared to the business-as-usual scenario to determine if the actions mitigated expected economic losses from climate change.

Table 5.14. Selected adaptation tactics for a confined dairy operation in the Ridge and Valley province of Pennsylvania.

Adaptation Actions		Time-frames	Benefits	Drawbacks & Barriers	Effectiveness and Feasibility of Tactic
Approach	**Tactic**				
Management Unit : Croplands					
1.1: Maintain and improve soil health	Follow corn silage harvest with planting small grains on fields with few environmentally sensitive areas	1-2 yrs.	Protects soil from raindrop impact Adds organic matter for soil biology to more efficiently cycle water and nutrients Living roots over the winter improve soil structure, biology, and water infiltration Provides another source of forage	Requires more management and labor during busy fall harvest season Feed ration needs adjustment to effectively use different source of forage	Moderately High
4.1: Reduce peak flow, runoff velocity, and soil erosion 4.2: Reduce severity or extent of water-saturated soil and flood damage.	Plant earlier maturing corn grain varieties in increasingly flood-prone areas to allow time for planting small grains or cover crop mixes	1-2 yrs.	Living cover tolerates flooding near streams or high-velocity water runoff better than residue from corn grain Corn grain residue may be harvested for use as fodder, bedding, or fuel	Small areas removed from corn grain production reduce field operation efficiency and may require more precision technology	Moderately High
1.2: Protect water quality	See same tactic described for the Farmstead Unit				
Management Unit : Farmstead					
1.2: Protect water quality	Cover waste storage facility and flare methane	3-5 yrs.	Risk of overtopping eliminated and community image protected Less rainwater collected and hauled	Gas emissions prevented from release Maintenance cost of cover and methane flaring Purchase costs	Moderately Low without financial assistance or increased consumer prices.
1.2: Protect water quality	Convert to solid liquid separation and manure injection nutrient application system	3-5 yrs.	Increased pumping efficiency Reduced hauling costs More manure nutrients available to crop Use of manure solids for livestock bedding offsets expensive wood shavings	Purchase costs Requires more management all year, possibly during busy spring planting season Risk of equipment failure and associated messes	Moderately Low without financial assistance or increased consumer prices

Glossary

Action—Something that is done or accomplished.

Adaptation (to climate change)—Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which reduces vulnerability, moderates harm, or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation (Intergovernmental Panel on Climate Change 2007).

Adaptive capacity—The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (Intergovernmental Panel on Climate Change 2007). This concept may be applied to natural or human systems and is synonymous with the concept of resilience (Smit and Wandel 2006).

Adaptive management—A decision process that promotes flexible decisionmaking that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process (Walthall et al. 2012).

Climate—Average weather conditions in given locations over time. The classical period for averaging climatic variables as defined by the World Meteorological Organization is 30 years. Climate influences a wide range of long-term activities and strategic decisions, from the types of crops grown to the design and construction of buildings, water delivery systems, and other infrastructure (Walthall et al. 2012).

Climate change—Statistically relevant changes in the mean state of climate or in its variability and that persist over extended periods of time, typically decades, centuries or longer. Changes may occur due to natural variations or a combination of natural variation and human-induced variation (National Atmospheric and Oceanic Administration 2016).

Climate variability—The inherent fluctuations or cyclical changes within the climate system beyond that of individual weather events. Variability may be due to natural internal processes within the climate system or to variations in natural or anthropogenic external forcing (Intergovernmental Panel on Climate Change 2007).

Effects (of climate change)—A change that is a result or consequence of climate change. The effects of climate change on agricultural production can be classified as either direct, indirect, or cumulative. Direct effects refer to the biophysical effects of changing abiotic climate conditions on crop and livestock growth, development, and conditions (Walthall et al. 2012). Indirect effects include biotic effects, such as those related to insect, disease, and weed pressure, as well as induced effects on input resources (land, water, soil) and market-mediated effects on input and output prices. Indirect effects of climate change may amplify or counteract the direct effects of climate change.

Impacts (of climate change)—Synonymous with "climate change effects" and refers to the positive and negative ways in which climate change will affect different systems.

Mitigation—With respect to climate change, an intervention to reduce the sources or enhance the sinks of greenhouse gases. (Intergovernmental Panel on Climate Change 2007).

Resilience—Resilience is the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks (Walker et al. 2002).

Risk—The potential for adverse consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values (Intergovernmental Panel on Climate Change 2007).

Social-ecological systems—A linked system of humans and nature in which the flow and use of resources (ecological, socioeconomic, and cultural) are regulated by the interaction of ecological and social systems. Agricultural social-ecological systems are ecosystems managed by humans to produce food and fiber for a set of interconnected markets (Walthall et al. 2012).

Uncertainty—A state of having limited knowledge where it is impossible to exactly describe the existing state, a future outcome, or more than one possible outcome (Walthall et al. 2012).

Vulnerability—The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (Intergovernmental Panel on Climate Change 2007).

Weather—The specific condition of the atmosphere at a particular place and time. It is measured in terms of parameters such as wind, temperature, humidity, atmospheric pressure, cloudiness, and precipitation (Walthall et al. 2012). Weather influences short-term activities and tactical decisions like crop planting, grazing, irrigation management, timing of manure and other nutrient applications, timing of pest suppression, harvesting, etc.

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APPENDIX 1:
Methods for Developing the Adaptation Strategies and Approaches

The **Adaptation Strategies and Approaches** described in Chapter 3 of this publication provide a menu of responses to help farm enterprises adapt to climate change. These serve as stepping stones to enable producers to translate broad concepts into targeted and prescriptive tactics for implementing adaptation. The methods and processes used to develop and refine this menu are described below.

Synthesis of Adaptation Literature

The compilation of adaptation strategies, approaches, and example tactics presented in Chapter 3 was developed using a process originally developed for identifying adaptation actions in forest ecosystems (Swanston and Janowiak 2012). The first step was to compile adaptation actions from a number of sources in both peer-reviewed and gray literature. Adaptation actions pertaining to on-farm production practices and infrastructure were included in this compilation, while actions related to farm financial management, technological developments (i.e., research and development), and government programs and insurance were omitted ((Smit and Skinner 2002; Walthall et al. 2012). The adaptation concepts and actions compiled from the literature were organized into a hierarchy of adaptation actions, from broad concepts to specific on-the-ground practices (see Figure 3.1). Based on expert review (see next section), adaptation actions were refined and organized into 8 strategies, 25 approaches, and more than 100 example tactics.

Expert Comment Process

We drew upon the experience and expertise of scientists, adaptation experts, and producers to provide input on how this expanded menu of adaptation strategies and approaches relates to a variety of agricultural commodities in the Midwest and Northeast, as well as other parts of the United States. We compiled a list of individuals with expertise in a variety of agricultural commodities, seeking representation from a variety of geographies and a balance of science and management from a range of institutions. Overall, more than 10 experts provided feedback, which was collected primarily through web-based survey software. For each adaptation strategy, experts were first asked a set of questions about the applicability of each adaptation approach under that strategy to agricultural production in the Midwest and Northeast. Experts were then asked to consider how effectively each of the associated approaches helped support the broader strategy. The questions were open-ended to allow reviewers to comment freely. Experts were asked to evaluate every strategy and every approach and to provide additional examples of adaptation actions (i.e., example tactics). This information was used to revise the initial list of Adaptation Strategies and Approaches.

Testing With Agricultural Professionals and Producers

A workshop hosted by the USDA Midwest Regional Climate Hub in March 2016 was used to test both the list of Adaptation Strategies and Approaches and the **Adaptation Workbook**. Following the workshop, changes were made to clarify important points and produce the final menu of Adaptation Strategies and Approaches presented in this publication.

ADAPTATION WORKBOOK WORKSHEETS

Worksheet #1: Define management goals and objectives.

Farm or Project Area:			
Location:			
Management Unit	Management Goals	Management Objectives	Timeframes

Worksheet #2: Assess site-specific climate change impacts and vulnerabilities.

Management Unit (from Step #1)	Regional Climate Change Impacts and Vulnerabilities	Climate Change Impacts and Vulnerabilities for the Farm or Project Area

Worksheet #3: Evaluate management objectives given projected impacts and vulnerabilities.

Management Unit (from Step #1)	Management Objectives (from Step #1)	Challenges To Meeting Management Objective With Climate Change	Opportunities for Meeting Management Objective With Climate Change	Feasibility of Objectives Under Current Management	Other Considerations

Slow down to consider...

Worksheet #4: Identify adaptation approaches and tactics for implementation.

Management Unit (from Step #1)	Adaptation Actions		Time-frames	Benefits	Drawbacks & Barriers	Effectiveness and Feasibility of Tactic	Recommend Tactic?
	Approach	Tactic					

Worksheet #5: Monitor and evaluate effectiveness of implemented actions.

Management Unit (from Step #1)	Adaptation Monitoring Variable	Criteria for Evaluation	Monitoring Implementation