

Climate Change Adaptation for Agriculture: Mitigating Short- and Long-Term Impacts of Climate on Crop Production

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Climate change¹ and climate variability pose a great risk to agricultural production and farm livelihoods, and producers will need to adapt to a changing climate that is expected to be significantly more variable in order to meet these challenges. Agricultural producers have a long record of successful *adaptation* to a host of internal and external pressures and have made remarkable strides in the face of these pressures. Yet the threat, and indeed, the reality of a changing climate puts our nation's food and fiber resources in peril. Recent years have demonstrated the vulnerability of our production systems to a changing climate and weather extremes. Indeed, 2012 was one of the most expensive years on record for crop damage (\$15.7 billion) and weather-related disasters.² The historic drought that gripped much of the Midwest and Eastern U.S. caused extensive crop damage and resulted in the largest ever government crop insurance payout. 2011 had a record-breaking 12 climate-related disasters that exceeded \$1 billion each. Thus, it is increasingly recognized that our production systems will need to exhibit even greater flexibility to remain viable. Figure 1 shows the historical yield increases our production systems are exhibiting and the impact of climate variability and extremes on yields. This publication outlines some of the climate-related challenges facing agriculture and then proposes some steps to *mitigate* and adapt to these challenges.

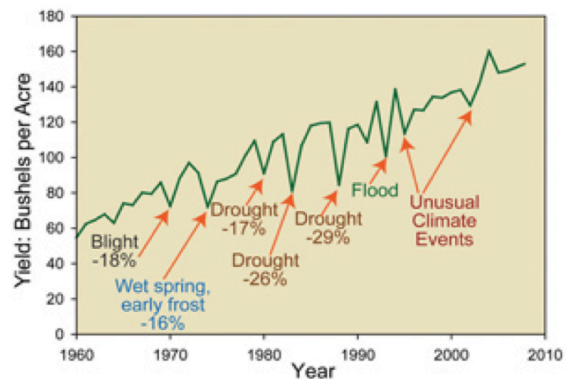


Figure 1. Despite technological and cropping improvements that increase corn yields, extreme weather events have caused significant yield reductions in some years. The unusual event in 1993 was destructive flooding of the Mississippi River; in 2003 the unusual event was a persistent heat wave.

Source: U.S. Global Change Research Program, 2009.

What Is Climate Change and What Are Its Consequences?

Certain activities create *greenhouse gases*, which capture heat and energy in the atmosphere and alter long-term climate cycles. This phenomenon is called the greenhouse effect. The Earth's greenhouse effect is, in fact, a natural phenomenon that helps regulate the temperature of the planet.

¹ Terms defined in the glossary are italicized the first time they appear in the text.

² Additional information can be found in the Resources section.

When the sun heats the Earth, some of this heat escapes back into space. The rest of the heat, also known as *infrared radiation*, is trapped in the atmosphere by clouds and GHGs, such as water vapor and *carbon dioxide* (CO₂). If all of these GHGs did not exist, the planet would be approximately 60 degrees (Fahrenheit) colder than it is today.

The primary GHGs emitted by human activities (fig. 2) are CO₂, *methane* (CH₄), and *nitrous oxide* (N₂O), which trap heat in the atmosphere and steadily increase the temperature of the Earth above natural levels. The levels of these gases are increasing at a rate faster than at any time during the past 100,000 years and are causing subsequent increases in global surface temperatures (fig. 3). Eleven of these years — 1995 to 2006 — set new annual global surface temperature records. The cumulative effects of increased GHG emissions and their role in the atmosphere and in weather patterns are known as climate change.

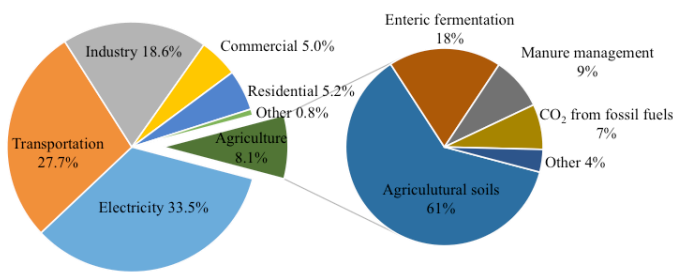


Figure 2. Contribution of agriculture to total U.S. greenhouse gas emissions and the breakdown of agricultural GHG emissions by source.

Source: Adapted from U.S. Environmental Protection Agency, 2011.

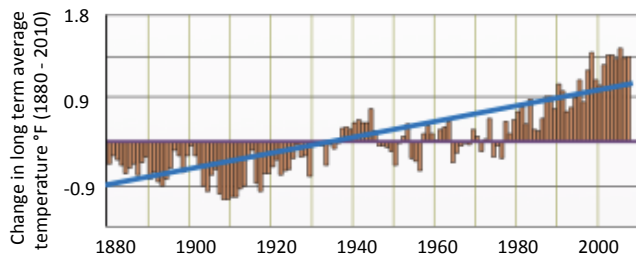


Figure 3. Annual global surface temperature departure from normal and trend, 1880-2010.

Source: National Oceanic and Atmospheric Administration, 2014.

The different GHGs have different potencies in the atmosphere. The potency of a GHG is referred to as its global warming potential and is commonly expressed as a carbon dioxide equivalent or CO₂e. Two common GHGs — methane and nitrous oxide — are 21 and 310 times more potent than CO₂, respectively; that is, their presence in the atmosphere traps considerably more heat than CO₂.

Scientists have concluded that increased temperatures are and will continue to significantly alter climate patterns, but the interactions are complex and a range of possibilities exists. According to the U.S. Environmental Protection Agency, certain regions of the U.S. will be more prone to extreme weather, such as tornados, drought, and flooding. Specifically, the Eastern U.S. is expected to experience more intense precipitation and longer periods of drought, also referred to as climate extremes or variability. This may appear contradictory, but in the Eastern U.S., the area affected by drought has increased steadily since the mid-1970s despite an overall annual increase in precipitation across the area.

Potential consequences of a changing climate include decreasing agricultural yields because of the rise in temperature and changes in precipitation, and the displacement of traditional crops northward, forcing producers to change the crops they can grow in order to adapt to the new climate. Increasing temperatures will also intensify the *water cycle*. Increasing *evapotranspiration* will make more water available in the atmosphere for storms but will contribute to drying over some other areas. As a result, storm-affected areas are likely to experience increases in precipitation and increased intensity, which can cause flooding, the loss of valuable topsoil, and crop damage. Areas located far away from storm tracks are likely to experience less precipitation and increased risk of drought. In the U.S., climate change is expected to cause a northward shift in storm tracks, resulting in decreases in precipitation in areas such as the Southwest U.S. but increases in many areas to the north and east. However, these changes will vary by season and will depend on regional weather patterns (e.g., El Nino, La Nina).

In a warming climate, extreme events like floods and droughts are likely to become more frequent. More frequent floods and droughts will affect water quality and availability. For example, increases in drought in some areas may increase the frequency of water shortages and lead to more restrictions on water usage, such

as for crop irrigation. An overall increase in precipitation may increase water availability in some regions but also create greater flood potential and water-logged soils, which can reduce crop production. Rising temperatures will also warm surface waters, causing them to be more susceptible to algae growth and making the control of *nonpoint source pollution* more critical.

Increased temperatures have several direct impacts on crop production as well.

1. Higher temperatures will cause more evapotranspiration, drying soils more rapidly and raising the humidity of the atmosphere, which can decrease crop water uptake. The implications of decreased crop water uptake and variable soil moisture level are not generally well-understood, but crops rely on water uptake to supply essential nutrients, so anything that decreases water uptake will need to be considered for its consequences on crop productivity.
2. Increased temperatures will reduce organic carbon levels in the soil via *oxidation*, which can further reduce soil moisture levels and subsequently impact crop productivity.
3. Increased temperatures may impact germination and senescence of some crops.
4. Reduced frost risk and warmer winters in many regions could allow earlier planting but could also expand the range of various agricultural pests and diseases.

Increased atmospheric CO₂ levels have the potential to increase crop productivity for two reasons.

1. Warmer temperatures may make many crops grow more quickly but could also consequently reduce yields of some crops. Crops tend to grow faster in warmer conditions, but for some crops, such as grains, rapid growth reduces the seed maturity and nutrition and can ultimately reduce yields.
2. Greater CO₂ concentrations increase plant respiration rates. As part of the carbon cycle, plants use energy from the sun to photosynthesize carbohydrate from CO₂, and greater CO₂ concentrations can result in greater carbohydrate production. A small amount of warming coupled with increasing

CO₂ could benefit certain crops, although the impact on crops depends also on the availability of water and nutrients.

Overall, scientists and policymakers generally agree that rapid climate change will have far more negative consequences on our production systems than positive outcomes. The supply and cost of food may change as farmers and the food industry adapt to new climate patterns. For warming of more than a few degrees, the effects are expected to become increasingly negative, especially for crops located near the warm end of their suitable temperature range.

Adapting to Climate Change

Adaptation Strategies

Adaptation covers many strategies that can reduce or mitigate the impacts of climate change and climate variability. Broadly, the term “adaptation” covers those practices that improve resistance to climate change, those that increase resilience to climate change, and those that transform production systems in the face of climate change. Some examples of these strategies include:

- Using drought-resistant or excess-moisture-resistant species (or varieties like drought-resistant wheat, corn, cotton, etc.) to reduce (resist) the impact from droughts and floods.
- Modifying crop rotations to include cover crops that help build resilience to climate change and climate variability.
- Installing controlled drainage systems to transform the landscape.

Conservation Practices That Mitigate Climate Impacts

Following are several practices that can help producers adapt to or mitigate the impacts of climate change.

Infiltration and Soil Water-Holding Capacity

Increasing the amount of rain that infiltrates into the soil and the *soil water-holding capacity* or available water content can reduce the impacts of both drought

and extreme rainfall events. As more water infiltrates, more can be stored in the soil and less runs off, which also reduces the probability of nutrient and sediment loss. One way to increase soil water-holding capacity is to increase the amount of *soil organic matter* in the soil profile. Soil organic matter can be increased by incorporating residue management practices and by practicing conservation tillage (see next practice).

Conservation Tillage

Conservation tillage reduces soil compaction and erosion and increases soil organic matter and infiltration capacity — all of which reduce runoff and increase drought resilience. Tilling the field exposes soil organic matter/carbon to oxidation and makes the soil more susceptible to erosion, both of which result in carbon depletion and, as a consequence, less productive soils. Advances in seed technology, pest control, and farm machinery are making no-till and reduced-till practices more acceptable to producers.

Cover Crops/Crop Rotations

Cropping sequences that include a fallow period tend to reduce soil carbon levels as compared to continuous cropping, which tends to increase soil carbon levels. Cover crops and nitrogen-fixing legumes are often recommended to both enhance fertility and increase the soil organic matter content. Cover crops also help ensure that soil is protected during intense rainfall events by absorbing raindrop impact, which reduces erosion and nutrient runoff; they also protect the soil during periods of drought, when wind erosion can remove topsoil. A greater number of rotations in any given crop rotation cycle (e.g., a five-year rotation versus a two-year rotation) can also help to reduce pest pressure, thus enhancing a field's productive capacity.

Controlled Drainage

In areas affected by both drought and excess moisture (e.g., extremes), new drainage practices have the potential to help maintain optimum soil moisture levels and root zone nutrient content, increasing crop productivity. These new systems can be actively managed to maintain water tables at a given level for a given crop growth stage, thus providing beneficial conditions for plant growth. As an added environmental benefit, some systems have also demonstrated reduced nutrient loss in drainage water, which also means more nutrients stay in the field, where they benefit the crop.

Irrigation Efficiency

Many regions already rely on irrigation during some portions of the growing season, and it is expected that the reliance on irrigation will increase substantially — both in traditionally irrigated crops and in those that will need to be irrigated due to increased temperature stress. This coupled with increasing per capita water demand will result in even greater stress on water resources. Thus, increasing irrigation efficiency will enable producers to irrigate more land with fewer resources. Practices such as regular system maintenance, frequent system audits, using recycled water, using drip or subsurface-drip irrigation systems, and incorporating soil moisture sensor networks to refine timing and target regions of a field are some common ways to improve irrigation water use efficiency.

Nitrogen Use Efficiency

Excessive rainfall can result in leaching of valuable nitrogen from the crop root zone. If nitrogen applications are optimized based on actual crop need, and — to the extent possible — applied when there is a low potential for leaching, yields and profits can be increased. Nutrient management tools that improve the timing, method, and amount of nitrogen applied should be used when possible. Some examples of these tools include nitrogen-content-sensing fertilizer applicators (e.g., GreenSeeker and many others), incorporating short- and long-term meteorological forecasts into fertilizer scheduling (e.g., evolving software tools such as Adapt-N), and utilizing soil moisture sensor networks to optimize timing. These strategies also decrease the amount of nitrogen that is lost to the environment.

Conservation Buffers (riparian, filter strips, etc.)

Conservation buffers, whether forested or grassed, increase the resilience of agricultural operations to weather extremes in multiple ways. Forested buffers along waterways can reduce streambank erosion and farmland loss during flood events. Grass strips within and surrounding fields help capture eroded soil and nutrients and can slow down runoff and prevent gully formation. Windbreaks help reduce soil loss from exposed ground during windy drought conditions. In addition, buffers increase carbon storage and provide habitat for valuable crop pollinators essential for some crops.

The Bottom Line

Contrary to some prevailing viewpoints, adapting to climate change will not necessarily involve an abrupt and fundamental shift in our production systems, although if actions are not taken soon, these abrupt shifts will be one of the few options available. By investing in intelligent agricultural practices, a producer might be able to increase crop productivity and profitability while also reducing the long-term economic risk from climate change.

Resources

Additional Resources

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Glossary of Terms

Adaptation – A response that seeks to reduce the vulnerability of biological systems to climate change impacts.

Carbon dioxide (CO₂) – Naturally occurring as well as gaseous product of fossil fuel combustion that, when released into the atmosphere, contributes to climate change.

Climate change – The aggregated long-term effects of increased temperatures and their role in changing climate and weather patterns.

Climate variability – Short-term (daily, seasonal) variations in climate, including those associated with El Nino or La Nina events.

El Nino – El Nino is periodic warming of the ocean waters in the eastern tropical Pacific that causes climate and weather abnormalities (increased precipitation) in much of the U.S. Also known as the Southern Oscillation.

Evapotranspiration – The sum of evaporation, which occurs from bare ground or open water, and transpiration, which is driven by plants.

Greenhouse gases (GHG) – A collection of human and naturally derived gases that trap heat within the atmosphere that can both regulate Earth's climate and contribute to climate change.

Infrared radiation – A form of energy not visible to the human eye but equally important as visible radiation on atmospheric processes. Often referred to as heat of radiation.

La Nina – The counterpart of El Nino. La Nina is characterized by unusually cold ocean temperatures in the eastern equatorial Pacific. It brings drier- and warmer-than-normal conditions for much of the Southern U.S.

Methane (CH₄) – A gaseous product of animal husbandry, among other sources, that contributes to climate change when released into the atmosphere (<http://epa.gov/climatechange/ghgemissions/gases/ch4.html>).

Mitigate – Make an activity less harmful by minimizing the source of harm.

Nitrous oxide (N₂O) – A gaseous product of denitrification and nitrification from agricultural fields, among other sources, that contributes to climate change when released into the atmosphere (<http://epa.gov/climatechange/ghgemissions/gases/n2o.html>).

Nonpoint source pollution – The result of many activities, including agriculture, nonpoint source pollution is transported intermittently by rain and nonrain (dry deposition) events alike. Also called diffuse pollution (as opposed to point source pollution that discharges from a defined origin, such as a pipe).

Oxidation – The conversion of matter (e.g., soil organic matter) to a less beneficial form by exposing it to oxygen.

Soil organic matter (SOM) – Plant and animal residues, cells and tissues, or soil organisms composed of carbon and the substances the organisms synthesize.

Soil water-holding capacity – Amount of water a given soil can store; primarily influenced by the soil texture and the soil organic matter content. In general, soils with greater silt- and clay-size particles have greater water-holding capacities. Likewise, soils with more organic matter have greater water-holding capacities.

Water cycle – Describes the movement of water through and between three phases (liquid, solid, and gas) aboveground and below. Also known as the hydrologic cycle.