Agriculture and Forestry in a Changing Climate: The Road Ahead

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25x'25
AMERICA'S ENERGY FUTURE

A Product of the 25x'25 Adaptation Initiative

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About the 25x'25 Adaptation Initiative

The effects of changing weather and climate present new challenges for farms, forests, and ranches. Though the causes of climate change are widely debated, its impacts will need to be addressed in order for agriculture to continue meeting the world's growing needs for food, feed, fiber, and fuel. Recognizing this, the 25x'25 Alliance has formed an Adaptation Work Group composed of agriculture, forestry, business, academic, and conservation leaders. Together, this group is exploring the impacts of a changing climate on the agriculture and forestry sectors and developing a prioritized series of recommendations for actions that should be taken by government agencies, universities, and business partners, as well as farmers, ranchers, and forest land managers to address adaptation challenges in the coming decades.

Executive Summary

As part of the first phase of the 25x'25 Adaptation Initiative, work group leaders examined current and anticipated shifts in climate and weather patterns that the agriculture and forest sectors will need to address in order to maintain and enhance future productivity and the delivery of ecosystem services. This document is a synthesis of information gleaned from peer reviewed scientific studies and reports on this subject.

The literature review revealed a number of important trends and impacts that farmers, ranchers, and foresters should be aware of:

- U.S. average temperatures are expected to rise by 4 to 11^{o}F by 2100, increasing nighttime temperatures, ozone, and the chances of heat waves and shortening winters; all of which will create stress on crops, forests, and animals. Though crop production might initially benefit from higher temperatures, as warming continues throughout the century, the risk of crop failure from higher temperatures will increase. High temperatures will also enable pests, pathogens, weeds, and other species to thrive in higher elevations and latitudes.
- Nationwide, very heavy precipitation events will continue to increase, raising concerns about flooding, runoff, and changes in land use. Droughts are expected to become more frequent, particularly for the Southwest, increasing fire risk to forests and stressing water systems.
- CO_2 levels are expected to increase in the coming decades. While this may benefit the production of some crops and forests, it will likely contribute to greater weed pressure, potentially requiring increased use of herbicides. Under higher CO_2 conditions, animal agriculture will face challenges from declines in forage quality, demanding greater consumption by livestock to acquire the same level of nutrients.
- Though the number of annual hurricanes may not increase, they are expected to become more severe, particularly in the Atlantic Ocean. Crops, forests, and agricultural infrastructure would be impacted by these major storms.
- Sea level is projected to continue rising. This will impact many coastal areas, rendering them more vulnerable to storm surges and resulting in changes in land use patterns.

Each of these projected changes, examined in greater detail in the full report, will present new opportunities and considerable challenges for the U.S. agriculture and forestry sectors.

While the 25x'25 Adaptation Work Group will update this document based on new findings, it will now serve as a resource for the next phase of the Adaptation Initiative: developing a prioritized series of recommendations for actions that should be taken by government agencies, universities, and business partners, as well as farmers, ranchers, and forest land managers to address adaptation challenges in the coming decades.

Introduction

In 2009, USDA placed the value of the U.S. farm and forest industries at $645 billion[1] which economists estimate generated over $1.2 trillion in related economic activity. Since 1950, food, feed, and fiber production have increased dramatically, enabling the United States to become the world's largest agricultural exporter. However, changes in climate and weather patterns are now threatening this continued progress and creating new challenges as the sectors prepare to support a world population that is projected to rise from 7 billion today to 9 billion people by 2050.[2]

In the years to come, scientists are anticipating:

- Increased carbon dioxide levels
- Higher temperatures
- Higher humidity
- More erratic and extreme weather events
- Greater risk of floods, drought and fire
- Rising sea levels

Each of these changes will pose considerable challenges for the agriculture and forestry sectors. In addition, these changes will not be uniform; rather, they will affect each sector and region of the country in very different ways.

Media reports and public discourse often portray climate change as something that will happen well into the future. However, many farmers, foresters, and ranchers throughout the United States are already witnessing the effects of changing climatic conditions. Whether it is thriving pests like the mountain pine beetle in the West, increases in heavy rainfall events in the Midwest and Northeast, or record droughts and wildfires in the Southwest, changes in weather patterns are currently costing billions of dollars in economic losses.

Scientists have similarly observed and

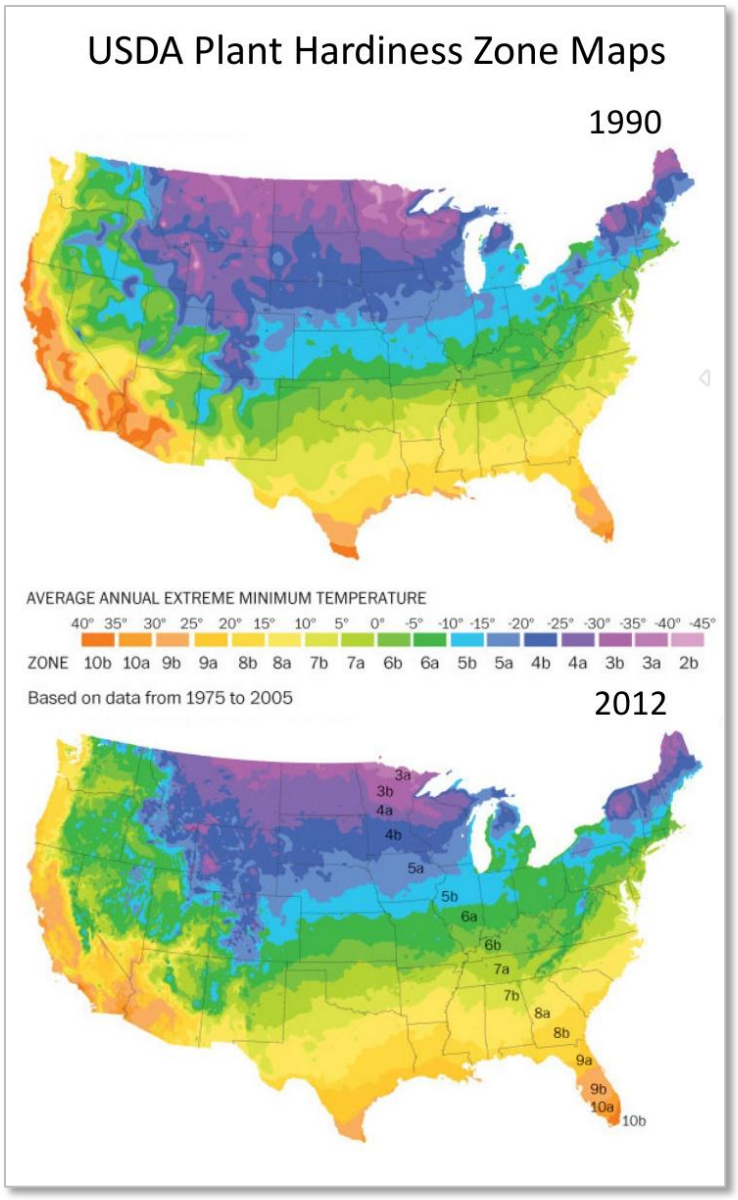

Figure 1 – In January of 2012, USDA released an updated version of its plant hardiness zone map. The difference between the new map and the 1990 version reflect a trend of planting zones moving northward.

documented these changes. Satellite data indicate that spring has been arriving nearly two weeks earlier in much of the U.S. during the last two decades.[3] Nationwide, intense rainfall events are on the rise and average U.S. temperature has risen more than 2°F over the past 50 years.[4]

A recent report by David Lobell, Wolfram Schlenker, and Justin Costa-Roberts in the journal *Science* helps shed light on what some of these changes have meant for corn and wheat production. The report concluded that for the past three decades changes in climate have reduced corn yields worldwide, relative to a stable climate, by 5.5 percent and wheat yields by 3.8 percent.[5]

2011 has produced numerous examples of ag and forestry's vulnerability to changing weather patterns. While scientists are careful not to associate any singular event with climate trends, 2011 marked a record year in the number of billion dollar weather-related disasters. The economic impact of these twelve disasters has been staggering, with the National Oceanic and Atmospheric Administration (NOAA) placing their total price tag at around $52 billion.[6] Included on this list was a drought in the Southwest that the Texas Department of Agriculture estimated had, through August 2011, cost the state's rural farm communities $5.2 billion.[7]

Extreme weather also had a significant effect on national crop insurance programs. While the final numbers are still being tabulated by the USDA Risk Management Agency for the 2011 crop year, as of January 2012, crop insurance companies had paid $8.89 billion in indemnities, exceeding the 2008 record of $8.6 billion.[8]

This background brief reviews some of the changes in climate anticipated by scientists and highlights research on the impact of these changes on agriculture and forestry. The information we have assembled was derived from a broad range of respected sources, including universities, government agencies, and internationally respected experts. All of the impacts mentioned within this document are areas where scientists have achieved consensus. Other conclusions, such as the general trends in tornado activity and thunderstorms have been omitted, as they are regarded as highly uncertain within the scientific community.[9] Also, while considerable research has been performed to determine the effects of various changes, scientists have the challenge of identifying not just the influence of a single variable (such as increases in temperature or CO_2), they must identify that variable's interaction with a multitude of other variables within the context of incredibly diverse and complex ecosystems. Additional research will be needed to uncover new challenges and opportunities as well as provide additional information through which informed decisions can be reached.

Anticipated Changes: Carbon Dioxide

Since the industrial revolution, the concentration of CO_2 in the atmosphere has increased significantly, from around 290 parts per million (ppm) in 1880, to over 380 ppm today (See Figure 2).[10] Researchers have developed a number of scenarios for atmospheric CO_2 concentrations from the present to the year 2100. Most of the references within the document will include a "higher emissions scenario" leading to CO_2 concentrations of around 850 ppm by 2100, and a "lower emissions scenario" of CO_2 that produces 550 ppm by 2100 (Figure 3).[11]

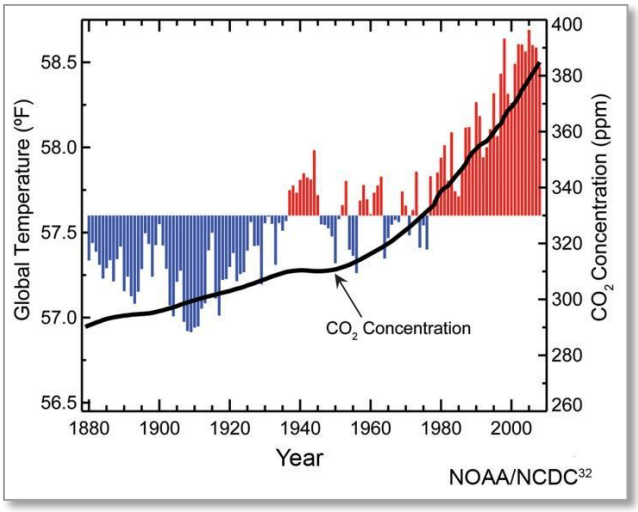

Figure 2 – From 1880 to the present, atmospheric CO_2 concentrations have increased along with temperature. The graph above shows this trend, with the red bars representing above average temperatures and blue bars representing below average temperatures for an individual year.

At first glance, increases in CO_2 appear to benefit forestry and agriculture. After all, plants use CO_2 for photosynthesis, leading many to suspect increased yields. Early research suggests that this may indeed be the case for some plants. The U.S. Global Change Science Program examined the current body of research on the effects of higher CO_2 concentrations on a wide variety of crops. As Figure 5 shows, soybeans, wheat, rice, cotton, peanuts, and beans experience substantial improvements in yield under higher CO_2 conditions. Higher CO_2 also caused some plants to require less water for growth.

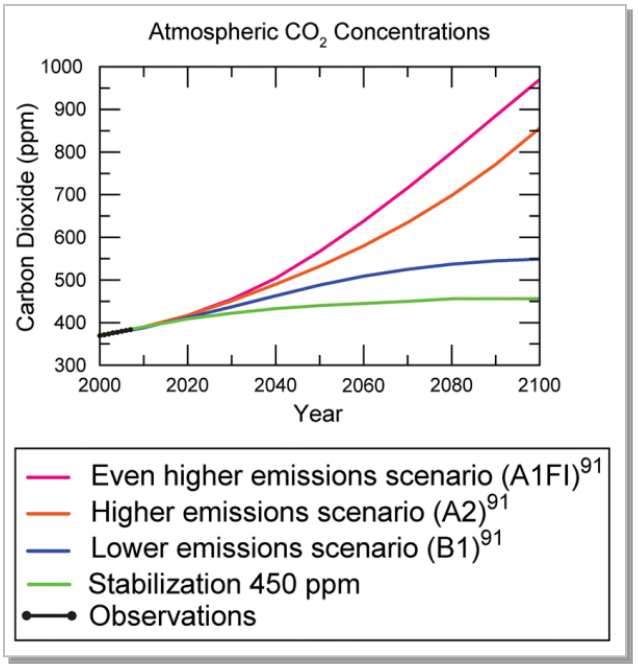

Figure 3 – Researchers use a number of atmospheric CO_2 concentration projections in order to determine scenarios for the impact of climate change. Under a lower emissions scenario, CO_2 concentrations only reach about 550 ppm by 2100. In a higher CO_2 scenario, concentrations reach 850 by 2100.

Yet there are reasons for crop producers to be concerned about rising CO_2 levels. The same factors that increase crop yields also benefit plants which farmers may not want to thrive, particularly C3 "invasive" weeds. Figure 4 shows the growth of weeds under different simulated CO_2 conditions. Both plots were treated with the same amount of RoundUp herbicide. Under higher CO_2 conditions weeds managed to thrive despite the herbicide, suggesting that high CO_2 conditions may require farmers to apply more herbicides more often, increasing input costs. Farmers currently spend around $11 billion a year on chemicals, the majority of which is spent on herbicides.[12]

Animal agriculture will similarly encounter problems. While higher CO_2 levels may increase crop yields, their feedstocks may not have the same nutritional quality. Plants grown in high CO_2 conditions have been found to have less nitrogen and protein content. To compensate for the poorer quality of grazing lands, animals may need to consume more. According to the U.S. Global Change Research Program, a high carbon dioxide simulation on shortgrass prairie reduced the protein concentration of fall forage below critical maintenance levels for livestock in 3 out of 4 years and reduced the digestibility of forage by 14 percent in mid-summer and 10 percent in fall. In the experiment, the grass type that thrived in the new conditions had the lowest protein concentration.[13] This reduction in plant quality could also cause insects, like livestock, to eat more crops in order to achieve the same nutritional value.[14]

Figure 4 - The left photo shows weeds in a plot grown at a carbon dioxide (CO_2) concentration of about 380 parts per million (ppm), which approximates the current level. The right photo shows a plot in which the CO_2 level have been raised to about 680 ppm. Both plots were treated with same amount of RoundUp herbicide.

Furthermore, CO_2 is seen by scientists as a driver in other climactic changes. An increase of CO_2 in the atmosphere is expected to bring higher temperatures, potentially exacerbating challenges such as extreme weather events and shifts in seasonality.

Crop	Leaf Photosynthesis	Total Biomass	Grain Yield	Stomatal Conductance	Canopy
	% change				
Corn	3	4	4	-34	
Soybean	39	37	38, 34	-40	-9,-12
Wheat	35	15-27	31	-33 to -43	-8
Rice	36	30	30		-10
Sorghum	9	3	8,0	-37	-13
Cotton	33	36	44	-36	-8
Peanut	27	36	30		
Bean	50	30	27		

Figure 5 – Above is a summary from the U.S. Climate Change Research Program of multiple studies on plant response to a doubling in CO_2 concentration (usually 350 to 700 ppm, but sometimes to 330 to 660 ppm).

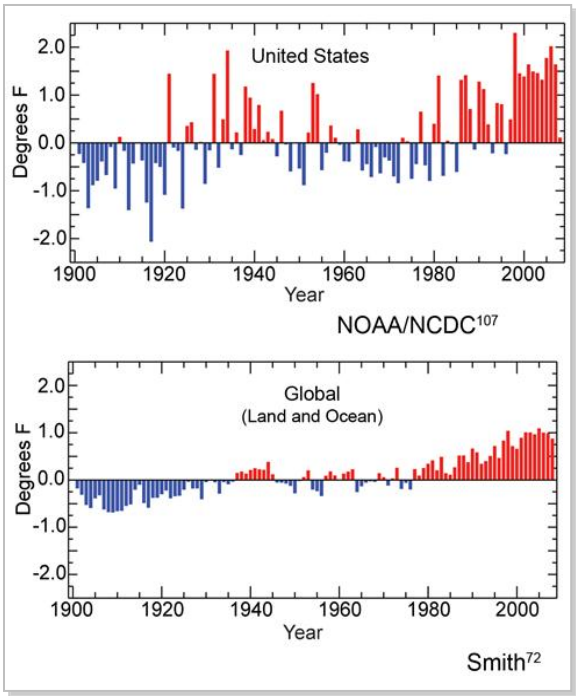

Figure 6 - From 1900 to 2008, temperatures have had an upward trend. Average temperatures within the U.S. have risen more than 2°F over the past 50 years

Anticipated Changes: Temperature

Average temperatures within the U.S. have risen more than 2°F over the past 50 years (Figure 6).[15] While that may not sound like a considerable change, such small alterations can have major implications on climate systems and agriculture. Furthermore, this number represents a change in average temperature for the nation. Certain regions, like Alaska, have experienced much greater changes.

As CO_2 and other greenhouse gases build within the atmosphere, scientists expect average temperatures to increase. The amount of this change, however, remains a subject of considerable debate. Researchers have developed a number of temperature scenarios based on atmospheric GHG concentrations. As shown in Figure 7, under a lower emissions scenario, they project U.S. average temperature to rise 4-6°F by 2090 from a 1961-1979 baseline. In a higher emissions scenario, temperature would likely rise from 7-11°F by 2090.[16]

Altered Growing Seasons

As with higher CO_2 levels, increased temperatures can have both positive and negative effects for agriculture. Climate change is expected to alter growing seasons. Crops like potatoes, lettuce, broccoli, spinach will experience shorter growing seasons. Whereas melon, okra, and sweet potatoes will have longer growing seasons.[17] Livestock producers could benefit from these longer growing seasons through additional forage production in late fall, reducing the need for winter storage.[18]

But longer growing seasons may have some significant downsides. For instance, they may necessitate additional water for irrigation and provide opportunities for insects to produce additional generations of offspring in a single season, threatening crops and livestock.

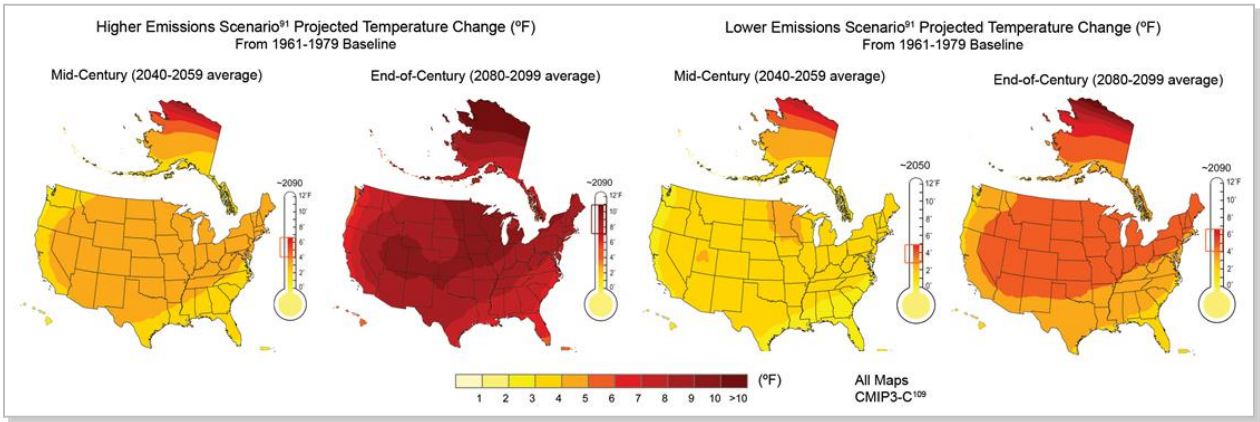

Figure 7 – Under both higher and lower scenarios of increased CO_2 concentrations, temperatures are expected to rise in the short and long-term throughout the century.

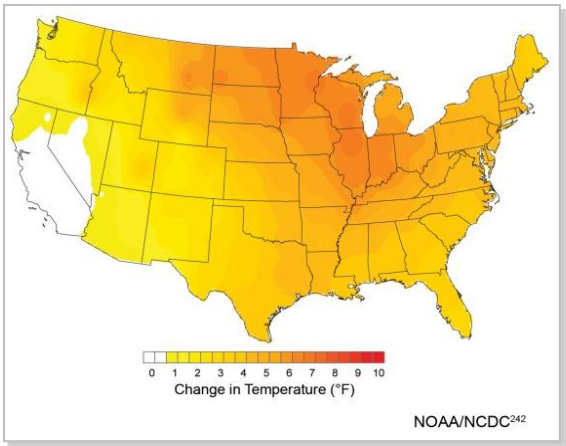

Figure 8 - This map reflects the changes in average winter temperatures across the nation from 1975 to 2007, using 1961-1979 as a baseline.

Crops and livestock will also be impacted by fewer extreme cold events in winter. Average temperatures have increased in winter more than any other season (See Figure 8)[19]. Higher winter temperatures can cause plants to bloom earlier, placing them at greater risk of frost exposure. This can also disrupt the crucial relationship between pollinators, like bees and birds, and flowering plants.[20]

In addition, cold winters play a vital role in limiting pests and pathogens. Warmer winters mean greater survival rates, requiring farmers to apply more insecticides, particularly in Northern climates and higher altitudes. The U.S. Global Research Program presents an example of the relationship between winter and pests, pointing out that Florida sweet corn growers spray their field 15 to 32 times a year to fight pests such as corn borer and corn earworm, while New York farmers spray zero to five times.[21] Under higher emissions scenarios, these numbers would likely climb for New York.

Cooler temperatures are also important to crops, particularly fruit and nut trees. Some require 400 to 1,800 hours below 45°F for high yields. Cranberries would no longer be suited for Massachusetts and New Jersey under higher warming scenarios, whereas the Great Lakes region would be improved for fruit production.[22] For the most part, the location suitable for crops is expected to move northward.

Warmer temperatures will also influence the availability of water resources. According to the United States Global Change Science Program, there is a trend toward reduced mountain snowpack and earlier spring snowmelt runoff peaks across much of the western United States.[23] Many agricultural communities rely on this snowpack as a valuable source of water. With this trend expected to continue, the West will likely augment water management to compensate for these changes and rely more heavily on groundwater sources.

Heat Stress

Heat waves are expected to become hotter, longer, and more intense.[24] Figure 9 shows the number of days reaching at least 100°F for 1961-1979. It then compares that number with lower and higher CO_2 emissions scenarios for 2080-2099. These events are expected to become more frequent, placing stress on crop and livestock yields and health.

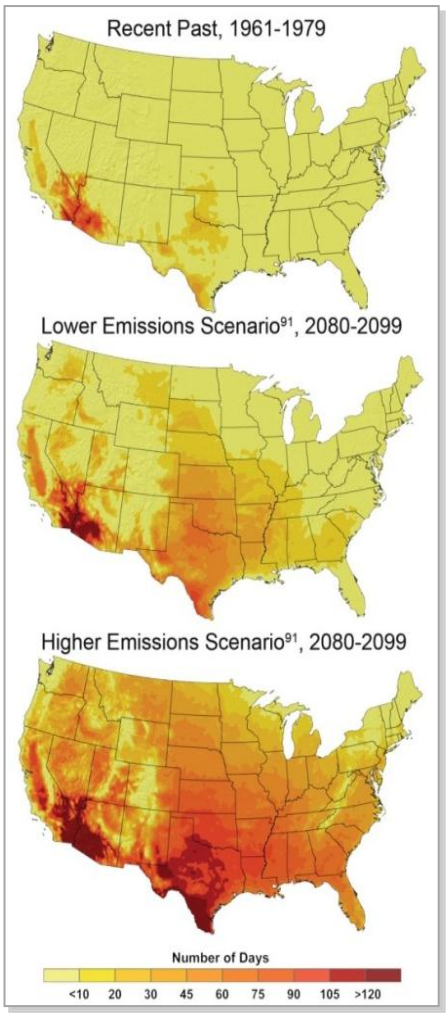

Figure 9 – These maps provide information on the number of days of at least 100ºF in the recent past, as well as projected 100ºF days under lower and higher CO_2 scenarios.

Most crops have optimal temperatures for growth and pollination. Increased temperatures can improve these processes, which is why some crops stand to benefit from initial temperature rises. For instance, where sufficient water is available, forest growth is likely to increase. But above each plant's optimal growth and pollination temperature, yields decline. At even higher temperatures, these processes can fail. Figure 10 provides the optimal temperatures for several key crops. Many grain and cereal crops like corn, wheat, sorghum, bean, rice, cotton, and peanuts[25] as well as tomatoes, onions, fruits[26] are especially sensitive to temperature changes. Higher temperatures will require plants to use more water, demanding additional irrigation in some parts of the country. Unfortunately, because high temperatures increase evaporation, there may less water available.

Crop	Base Temp Veg	Opt Temp Veg	Base Temp Repro	Opt Temp Repro	Opt Temp Range Veg Prod	Opt Temp Range Reprod Yield	Failure Temp Reprod Yield
Maize	46.4	93.2	46.4	93.2		64.4 - 71.6	95
Soybean	44.6	86	42.8	78.8	77 - 98.6	71.6 - 75.2	102.2
Wheat	46.4	78.8	33.8	78.8	68 - 86	59	96.2
Rice	46.4	93.8	46.4	91.4	91.4	73.4 - 78.8	95 - 96.8
Sorghum	46.4	93.2	46.4	87.8	78.8 - 93.2	77	95
Cotton	57.2	98.6	57.2	82.4 - 86	93.2	77 - 78.8	95
Peanut	50	>86	51.8	84.2 - 91.4	87.8 - 95	68 - 78.8	102.2
Bean					73.4	73.4 - 75.2	89.6
Tomato	44.6	71.6	44.6	71.6		71.6 - 77	86

Figure 10 – The U.S. Climate Change Science Program examined, for several economically significant crops, information regarding base and optimum temperatures (ºF) for vegetative development and reproductive development, optimum temperature for vegetative biomass, optimum temperature for maximum grain yield, and failure (ceiling) temperature at which grain yield fails to zero yield.

Heat stress could be especially hard on livestock. Under high temperatures animals experience reduced weight gain, decreased milk and egg production, and lower reproduction. Moreover, sustained high temperatures render livestock more susceptible to parasites and other pathogens. The culmination of these factors was shown in heat waves experienced in the Midwest in 1995 and 1999 which resulted in the loss of nearly 5,000 head of cattle in each event.[27] One study concluded that a 2.7°F warming would cause less than a 1 percent decline in livestock yields in cow/calf and dairy operations in Appalachia, the Southeast, and the Southern Plains. But, under a higher emissions scenario, where warming could be in the range of 9 to 11°F, a 10 percent decline would be expected.[28]

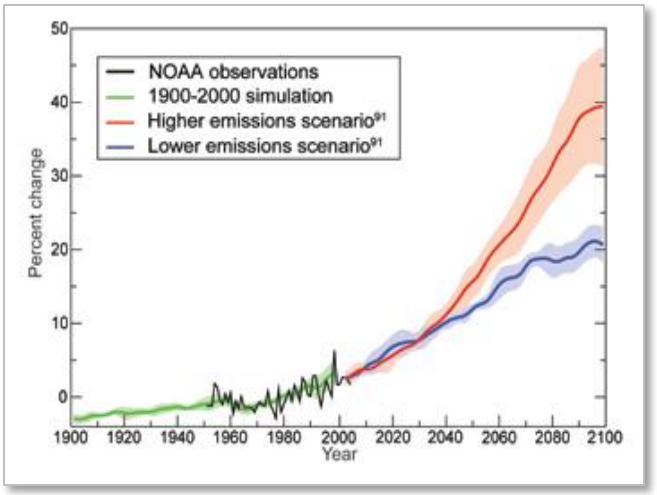

Figure 11 – This graph shows the observed and projected changes in very warm nights.

The problem of heat stress is compounded by a projected rise in nighttime temperatures. Since 1970 the percentage of very warm nights has increased (Figure 11). Under a lower emissions

scenario, very warm nights (using 1961 to 1990 as a baseline) would increase 20 percent by 2100. Under a high scenario, they rise by 40 percent.[29]

Moreover, nighttime temperatures increase plant respiration rates, limiting the amount of carbon that be captured during the day by fruit and grain crops. Similarly, without significantly reduced evening temperatures, livestock do not get a sufficient recovery from day-time heat.

Rising temperatures are expected to be accompanied by increases in high humidity events, requiring more spraying for crop pathogens favored by moist conditions and increasing discomfort and respiratory problems for livestock.

Ozone

High above the earth in the stratosphere, ozone (O_3) serves as an important shield of protection against harmful UV rays from the sun. But at the ground level (troposphere), ozone is a harmful pollutant. Unlike other gases, O_3 is not usually emitted into the air. Instead, it is formed by a reaction between sunlight and hydrocarbons with nitrogen oxides largely from industrial emissions and motor vehicle exhaust.

As temperatures and sunlight increase, ozone concentrations rise. Ozone is toxic to most plants, but appear to be especially harmful to soybean, wheat, peanuts, and cotton. The majority of research into the effects of ozone has been conducted on soybeans. Studies suggest that even mild but sustained exposure (40-60 ppb) can reduce yields by 24 percent and biomass by 34 percent.[30] According to a 2009 study led by Rita Van Dingenen, current global yield losses due to ozone are between 7% and 12% for wheat, 6% and 16% for soybean, 3% and 4% for rice, and 3% and 5% for maize.[31]

In the past 50 years, the amount of low level ozone has gone up, particularly for rural areas.[32] In fact, the Midwest and eastern U.S. have some of the highest rural ozone levels in the world.[33] These trends are expected to continue with temperature increases over the course of the century.

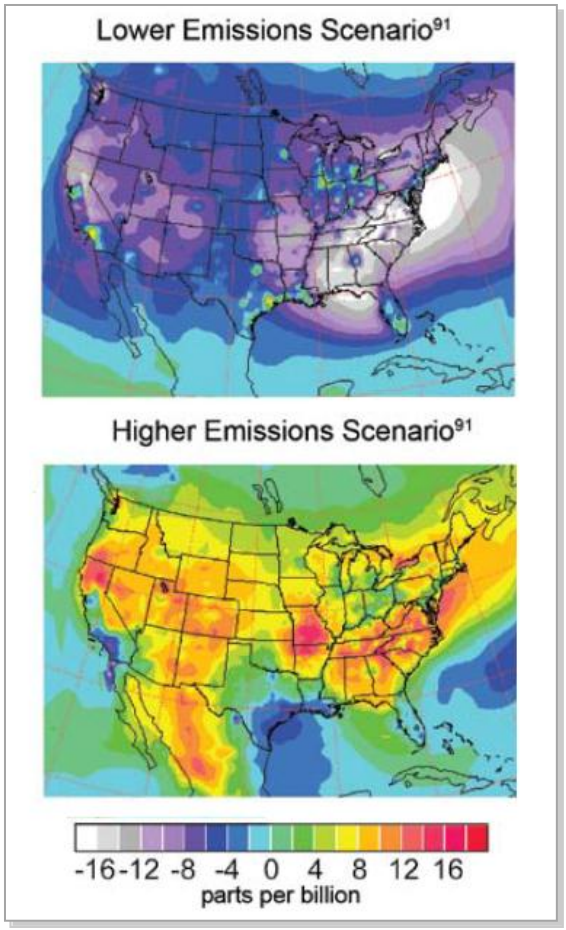

Figure 12 – Under a higher emissions scenario, ozone is expected to increase throughout a vast majority of the U.S.

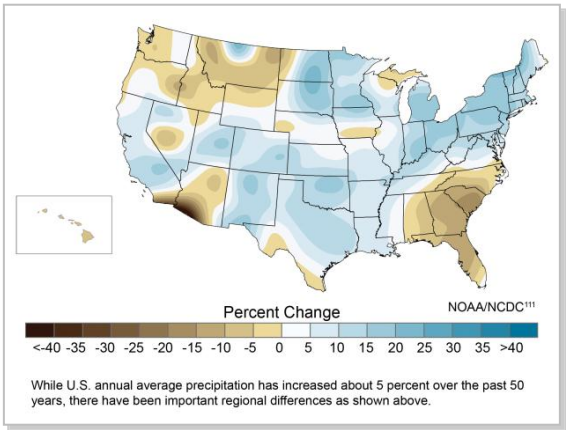

Figure 13 - This map shows changes in annual rainfall over the past 50 years. During this period, U.S. rainfall has increased about 5%

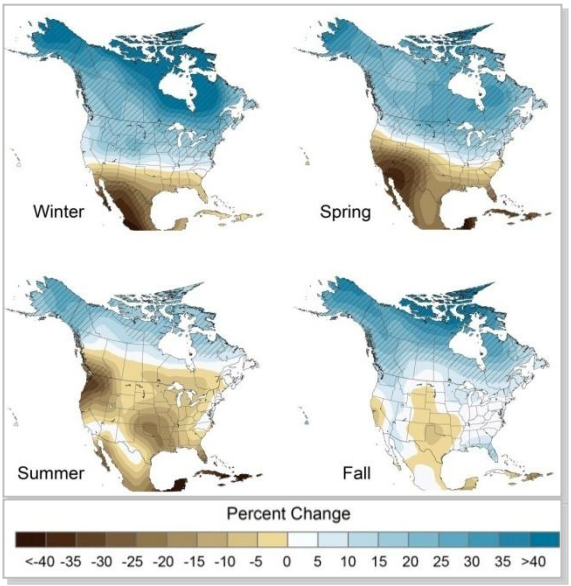

Figure 14 - Projected Change in North American Precipitation by 2080-2099 under a higher CO_2 concentration scenario.

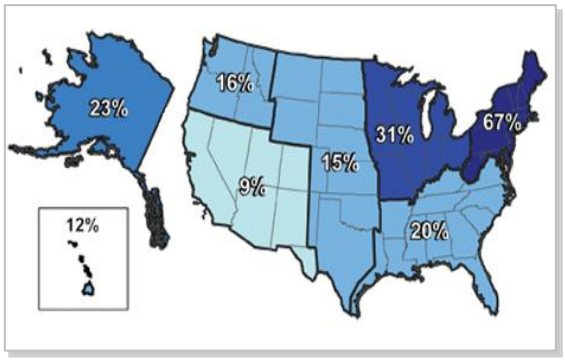

Figure 15 – This map shows increases in very heavy precipitation events from 1958 to 2007. This trend is expected to grow worse in the decades ahead.

Anticipated Changes: Precipitation

Over the past 50 years, U.S. rainfall has increased about 5 percent.[34] While this number is not significant, change in rainfall has varied regionally, with the Northeast becoming wetter and portions of the Southwest and Northwest becoming drier. Figure 12 shows a nationwide breakdown of the changes in precipitation over the past 50 years.

Although total rainfalls may not have increased significantly, the seasonal variation of rainfalls has. The Southwest experienced a decline in rainfall for all seasons except fall. In the Northwest, only spring had increased rainfall. Overall precipitation decreased in summer. In projecting future rainfall, scientists expect this summer trend to continue (Figure 14). In general, the southern portion of the U.S. is expected to become drier, raising concern about the needs for improved water efficiency and water management. The Northern portion of the U.S. is expected to get wetter, particularly in the winter months, increasing flood risk and disruptions in spring planting.[35]

Heavy Rainfall Events

Of particular concern to scientists is an increase in rainfall during very heavy precipitation events, defined as the heaviest 1 percent of all events. Throughout the U.S., there has been a 20 percent increase in these events (Figure 15). This change has been the most notable for the Midwest (31 percent) and Northeast (67 percent).[36] According to the U.S. Global Change Research Program, by the end of the century, events that are now 1-in-20 year occurrences are projected to occur about every 4 to 15 years.[37]

This change could have significant implications for agriculture. Apart from delays in planting and harvest, heavy rainfalls increase the risk of flooding and crop loss. They also intensify loss of topsoil, root diseases, and soil compaction. In terms of water quality, heavy rainfalls often lead to more runoff of chemicals and nutrients into stream ways, increasing low oxygen (hypoxia) water problems.

Furthermore, many places in America that have seen

so called “100-year floods,” and even “500-year floods,” become more frequent, are redrawing their flood maps. These changes will make insurance near riparian areas more expensive and likely force new limits on federal insurance programs. They will also generate interest in declaring new floodplains. The initial findings of a new assessment being conducted for the Federal Insurance Program suggest that flooding from stronger storms could increase the size of areas declared floodplains by 45 percent by 2100.[38]

Drought

While droughts have become less frequent in the Midwest and Great Plains over the last 50 years, they have reached unprecedented levels in the Southeast and West. As with heavy rainfall, this pattern is expected to grow worse throughout the century,[39] necessitating changes in water systems and water management in order to meet the needs of agriculture.

Droughts lead to increased erosion and additional strains for plants and livestock, making them more vulnerable to other threats, such as insects.[40] The record pine beetle infestations that have devastated 4 million acres of forests in the West are likely connected to decreasing water resources. When pines are under stress, their ability to produce resin that entraps and kill the beetles decreases.[41]

Fire risks also surge under drought. Lowered rainfall in the Southwest is recognized as a factor in the “mega fires” experienced in summer 2011. Over 6 million acres have already been burned in the United States through August of 2011, up from about 2 million acres at this time the previous year, and far above the 10-year average of 4 million.[42] The pine beetle infestation is believed to have exacerbated these problems since the dead trees hold around one tenth as much moisture as living ones, causing them to ignite faster and burn more intensely.[43]

Anticipated Changes: Hurricanes

The impact of higher temperatures on hurricanes has received much media attention. While scientists are not certain whether hurricanes will occur more frequently in the future, they do believe that hurricanes will become more intense because of increases in surface level ocean temperature. Over the past 30 years, annual sea temperatures in the main Atlantic rose by approximately 2°F. This change has corresponded with an increase in storm strength, particularly for category 4 and 5 hurricanes, translating into stronger winds and higher rainfalls which, upon landfall, threaten crops, livestock, and infrastructure.[44]

Anticipated Changes: Sea Level

Over the last 50 years, sea levels have risen. For many areas along the Atlantic, this rise has been at least 8 inches.[45] This change is occurring because of the transfer of fresh water from melting, in-land glaciers coupled with the expansion of the ocean due to increased temperatures (thermal expansion). Though scientists are fairly confident about the reasons for sea level rise, the amount of rise expected remains a subject of contention. There have been a wide range of sea level scenarios. The 2007 Intergovernmental Panel on Climate Change (IPPC) report suggested a range in sea level rise of 8 inches to 2 feet. However, newer studies have put the range for higher emissions scenarios between 3 to 4 feet by 2100.[46] In addition to reducing available land, rising sea levels increase the risk of storm surges, especially when coupled with intensified hurricanes, threatening damage to agricultural lands and increased public demand for the conversion of coastal lands from development.

Conclusion

Though there remain many unanswered questions about projected changes in weather and climate and their impacts, what we do know for certain is that they present a less predictable, less stable environment for farmers, foresters, and ranchers; one where business as usual may not be enough to meet the needs for food, feed, fuel, and fiber of a rapidly growing world.

Given the magnitude of the challenges that changing climate and weather patterns will likely create, the 25x'25 Adaptation Work Group is developing recommendations for actions that should be taken by government agencies, universities, business partners, and producers to address adaptation challenges in the coming decades. These recommendations will cover a wide range of areas, from highlighting the need for additional research and communication tools to identifying adaptation policies and best practices.

This critical work, however, cannot be accomplished by this group alone. We invite partners to join us in this important conversation and exploration of solutions.

To Provide Comments or for More Information

To provide comments or for more information on this brief or the 25x'25 Adaptation Initiative, contact Tim Fink at tfink@25x25.org or 410-252-7079. Additional information on the 25x'25 Alliance can be found online at www.25x25.org.

Additional Resources

For more information on these topics, consult the following resources:

USDA Climate Change Program Office (CCPO)

Website: http://www.usda.gov/oce/climate_change/index.htm

CCPO serves as USDA's focal point for climate change issues and is responsible for coordinating activities with other Federal agencies, interacting with the legislative branch on climate change issues affecting agriculture and forestry, and representing USDA on U.S. delegations to international climate change discussions. The site contains links to USDA climate change programs and websites. Major USDA climate change resources available on the site include:

1. Synthesis and Assessment 4.3: The Effects of Climate Change on Agriculture
2. U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990-2008
3. USDA Climate Change Science Plan

USDA Economic Research Service: Climate Change Briefing Room

Website: http://www.ers.usda.gov/Briefing/GlobalClimate/

The ERS climate change program focuses on the economic implications of climate change for U.S. agriculture. This briefing room describes the ERS climate change research program and provides

background information related to climate change and U.S. agriculture. Numerous ERS reports, web links, and other resources related to a wide range of climate change issues of interest to U.S. agriculture are also available on this site.

U.S. Global Change Research Program

Website: http://www.globalchange.gov/

The U.S. Global Change Research Program (USGCRP) coordinates and integrates federal research on changes in the global environment and their implications for society. This site contains links to climate change resources located throughout the thirteen departments and agencies that support climate change science programs. The full set of Synthesis and Assessment Reports that made up the last U.S. climate change assessment are available on this site.

Nicholas School of the Environment: Climate and Energy Program

Website: http://www.nicholas.duke.edu/

The Nicholas School at Duke University is a leading academic institution doing research on a wide range of environmental issues. The climate and energy program draws upon Duke's expertise in the areas of economics, science, law, engineering, and finance to develop and evaluate strategies aimed at reducing greenhouse gas emissions and stimulating novel energy investment. The site contains numerous reports, white papers, and other products assessing the economic implications of various policy approaches to a wide range of climate change issues of interest to U.S. agriculture and forestry.

Forestry and Agriculture Greenhouse Gas Modeling Forum

Web site: http://foragforum.rti.org/index.cfm

Every two years USDA, US EPA, and Agriculture and Agri-Food Canada sponsor the Forestry and Agriculture Modeling Forum. The Forum brings together leading members of the climate change modeling and policy communities for the purpose of facilitating dialogue on the current status of modeling capabilities, likely advances in modeling capabilities over the next two years, and the information needs that policy makers view as highest priorities to fill. To date there have been six meetings of the Forum. Organizing themes vary across meetings to reflect topic areas of current interest. Reoccurring areas of focus include key modeling and policy design priorities, climate change adaptation and food security, greenhouse gas mitigation, bioenergy, deforestation, and REDD. The forum web site is maintained by Research Triangle Institute and contains agendas, presentations, and participant lists from all six meetings

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Figure 2 – United States Global Change Research Program, "Global Climate Change Impacts in the United States," 2009, pg. 17.

Figure 3 – United States Global Change Research Program, op. cit, pg. 23.

Figure 4 – United States Global Change Research Program, op. cit, pg. 75.

Figure 5 – Adapted from United States Climate Change Science Program, "The effect of climate change on agriculture, land resources, water resources, and biodiversity in the United States: Program synthesis and assessment product 4.3," 2007, Washington, D.C., pg. 35.

Figure 6 – United States Global Change Research Program, op. cit, pg. 27.

Figure 7 – Adapted from United States Global Change Research Program, op. cit, pg. 29.

Figure 8 – United States Global Change Research Program, op. cit, pg. 76.

Figure 9 – United States Global Change Research Program, op. cit, pg. 29.

Figure 10 – Adapted from United States Climate Change Science Program, op. cit, pg. 26.

Figure 11 – United States Global Change Research Program, op. cit, pg. 73.

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