WRITTEN TESTIMONY OF:

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Key Points

- Climate change is impacting agriculture and forestry by raising temperatures, which: affect the length of the growing season, degree days and chill hours; cause heat stress affecting livestock and outdoor workers; enhance evapotranspiration; and increase the likelihood of extreme events like floods and droughts, all of which have negative consequences on farm production.

- Agricultural and forest-based practices are affecting climate change by adding greenhouse gases to the atmosphere and altering the soil and land used for growing crops and livestock, adding to the rise in temperatures through release of methane and other greenhouse gases.

- Producers can reduce their emissions of greenhouse gases by using climate-smart agricultural practices such as using more cover crops and precision irrigation and by reducing food waste and overuse of fertilizers and other agricultural chemicals, which will help slow warming.

- Producers are already adapting to changes in climate by adding cover crops, changing crop and tree varieties, and adding new crops to their farms as well as adding cooling structures and irrigation; these actions can make their farms more resilient to changing climate and extreme weather.

- Farmers can benefit economically from conserving water, fuel, and labor now while they are helping to reduce climate change by managing their land and animals carefully.

- As farming and forestry become more technologically advanced, new management tools will require access to more and better local data to help producers make smart choices about how they manage their farms and forests for health, safety, and profit.

Introduction

I would like to thank Chairman Scott and the other members of the House Agriculture Committee for the opportunity to testify at this hearing to explore the relationship between agriculture and forestry and climate change. It is an honor and privilege to be with you today. My name is Pamela Knox, and I am a Public Service Associate with Cooperative Extension at the University of Georgia. I am currently the Director of the University of Georgia Weather Network and an Extension Specialist in agricultural climatology. I have worked on projects specifically related to agriculture, forestry, and climate change for the last decade. Prior to my current position, I was a research scientist funded by the U. S. Department of Agriculture (USDA) to study the impacts of climate variability and change on crop production in the Southeast and on livestock production across the United States. I also worked with the USDA Southeast Regional Climate Hub to identify how climate variability and change affect management decisions and day-to-day activities on working lands across the region. I am currently a co-Principal Investigator on two projects related to identifying the rapid onset and expansion of drought using soil moisture monitoring; one is funded by USDA and the other by NOAA. I am a previous President of the American Association of State Climatologists and have served as State Climatologist in Wisconsin and as Assistant State Climatologist in Georgia. I am also a Certified Consulting Meteorologist and have served as the Chair of the American Meteorological Society's Board on Certified Consulting Meteorologists as well as their Board of Professional Continuing Education and on their Standing Committee on Applied Climatology. My testimony today is my opinion, based upon my background and experience in studying agriculture and climate.

Overview

According to the Bible and other ancient texts, agriculture is one of the earliest signs of civilization. Agriculture and forestry provide us with the food we eat, fiber we use to make clothing, and building materials and fuel that we use to provide shelter and keep us warm. In the United States in 2019, agriculture contributed over $1.1 trillion dollars to the GDP, a 5.2 percent share of the economy.[1] In addition, agriculture provided 10.9 percent of total U. S. employment.

Of all the sectors of the U. S. and the world economy, agriculture is arguably the one most affected by swings in weather and climate. Natural cycles of climate variability in the past have led to changes in agricultural activity as temperatures have risen and fallen and rain has come and gone. In periods when the local climate is favorable, those communities have expanded. Where drought, frosts, and extreme heat have occurred, agriculture has contracted and sometimes failed, leading to famine and migration as the citizens moved elsewhere or died out. Agriculture has also affected the communities around it by changing the nature of the land cover from forests to bare fields, affecting the local energy balance, temperature, and water cycle. In areas where agriculture expanded beyond the capacity of the local climate to sustain it, the land lost its ability to provide for those who lived there.

Agriculture has also benefited from the rise of the Industrial Revolution, which provided agricultural producers with the mechanical ability to farm larger acreage, reduce the impacts of pests and diseases,

[1]https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/ag-and-food-sectors-and-the-economy/

and increase yield through the use of fertilizers and other agricultural chemicals. This has allowed us to feed a growing population. These benefits did not come without costs, however, since use of mechanical equipment requires fuel and factory production. Agricultural chemicals, when used improperly, have hurt natural ecosystems and contributed to the growth of toxic algae and diseases in water downstream. The cost of using this modern equipment has also put economic strain on lower-income and minority farmers who often have difficulty getting access to the most recent technology and information needed to maximize their potential yields. Clearing of land has reduced forest cover in some areas and released carbon dioxide and other greenhouse gases into the atmosphere, resulting in changes to the earth's energy balance.

Since 1895, annual average temperature in the United States has changed quite a bit from year to year (Figure 1), making planning for farmers difficult since what happened last year is probably not what they will experience this year. The annual average temperature has also changed on longer time scales due the influence of both natural cycles and human contributions to the global energy balance. Natural cycles include both shorter-term cycles such as the El Niño Southern Oscillation (ENSO) related to ocean temperatures in the eastern Pacific Ocean, and longer-term cycles in the global atmosphere and ocean. Those natural cycles occur on top of an upward trend that has been linked in numerous studies to increasing greenhouse gases in the atmosphere, which act as a blanket that holds the earth's heat near the

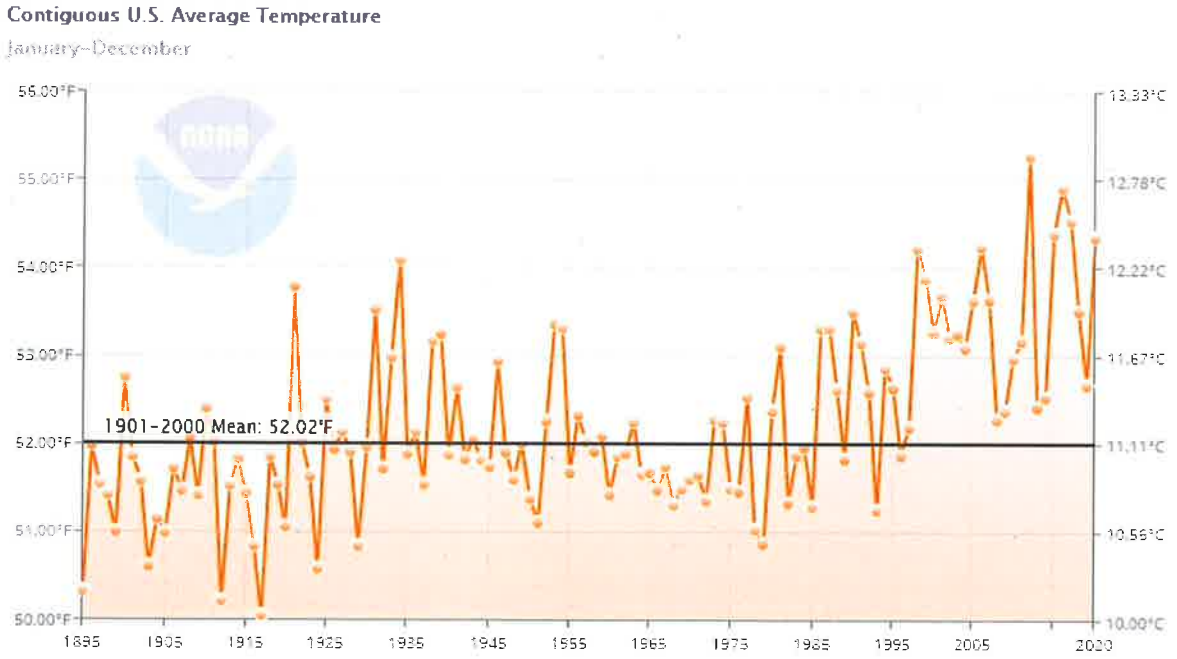

Figure 1. Contiguous United States annual average temperature from 1895-2020.[2]

[2] NOAA National Centers for Environmental information, Climate at a Glance: National Time Series, published February 2021, retrieved on February 10, 2021 from https://www.ncdc.noaa.gov/cag/

surface instead of allowing it to escape to space. In the 57-year average lifetime of a farmer in the United States[3], the average temperature has risen by approximately 2 degrees F. Overnight low temperatures have increased more than daytime high temperatures[4], which may be due to increases in humidity over time or to differences between the structures of daytime and nighttime atmospheric layers near the ground[5]. This is important for agriculture because warmer nights hurt early-morning workers and prevent steers from gaining weight due to 24-hour warmth[6].

The annual average precipitation of the contiguous United States has also increased during that farmer's lifetime (Figure 2). As temperatures rise, the atmosphere can hold more water vapor than before. The result: as the water cycle has strengthened, both humidity and temperature have increased. That has not eliminated the year-to-year swings that occur naturally due to ENSO and other internal cycles in the global climate system, so farmers still need to be able to respond to the short-term changes in rainfall, including droughts and floods, as well as plan for long-term changes that the warmer climate will bring. Precipitation is also becoming more variable, with more rain on the wettest days and longer dry spells between rainstorms[7].

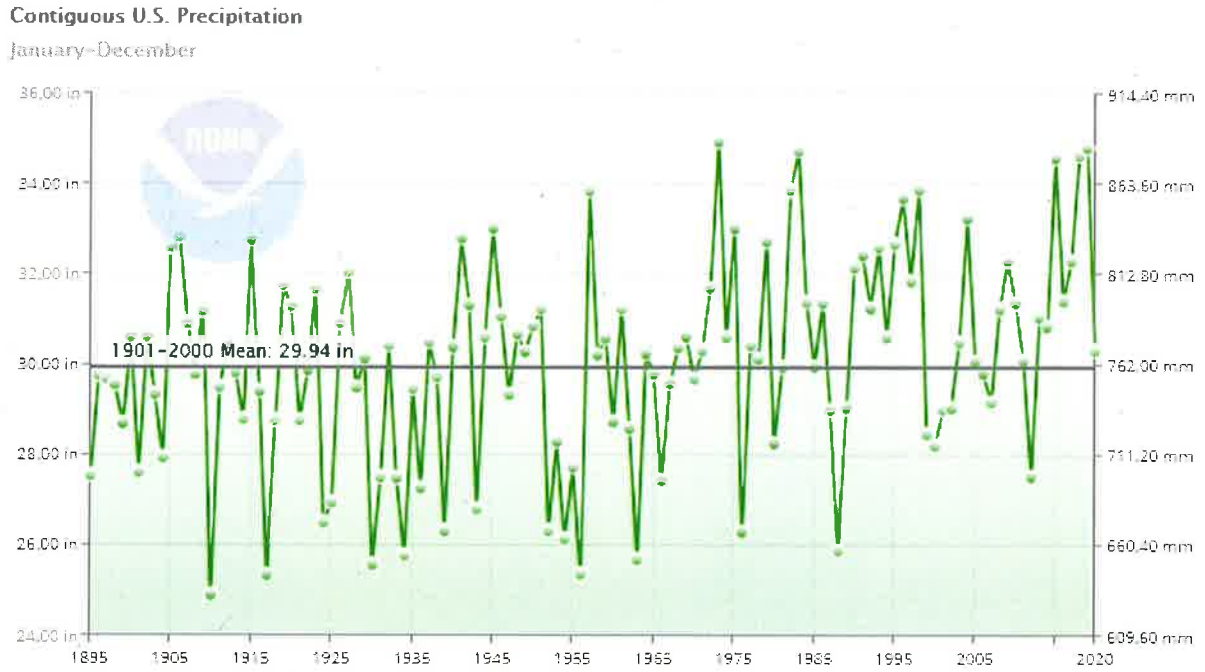

Figure 2. Contiguous United States annual average precipitation.[8]

[3] 2017 Census of Agriculture, USDA National Agricultural Statistics Service
[4]https://science2017.globalchange.gov/chapter/6/.
[5] https://phys.org/news/2016-03-nights-warmer-faster-days.html
[6] https://www.climate.gov/news-features/blogs/beyond-data/climate-change-rule-thumb-cold-things-warming-faster-warm-things
[7] https://www.epa.gov/climate-indicators/climate-change-indicators-heavy-precipitation
[8] NOAA National Centers for Environmental information, Climate at a Glance: National Time Series, published February 2021, retrieved on February 10, 2021 from https://www.ncdc.noaa.gov/cag/.

Changes in temperature and precipitation are also affecting the frequency and intensity of extreme events, including heat waves, floods, droughts, and severe weather like hurricanes and derechos, such as the one that devastated parts of Iowa last August. Floods have become more frequent and damaging due to a more active water cycle and increases in vulnerable infrastructure. This infrastructure was built to design standards for the past climate, which may not reflect what we are seeing now or will occur in the future. Droughts have become more frequent and often start and grow more quickly than in the past due to warmer temperatures and longer dry spells between rain events. We call these quickly developing droughts "flash droughts," an area I study in my work. These droughts have a special impact on agriculture because crops and forage need regular amounts of water to grow and thrive, and if they do not get it, they can lose health and potential yields very quickly.

Hurricanes and tropical storms so far do not seem to be increasing in number overall (although there is a lot of year-to-year variability based on natural cycles). However, recent research has shown that hurricanes are moving more slowly over land than they have in the past and are intensifying more rapidly just before they make landfall, which increases the damage they can do to coastal areas and crops that lie along the path of the storms after they come onshore[9]. Extreme wind events such as tornadoes and derechos also do not appear to be increasing in number[10], although they may cause more damage than in previous years due to increases in shade trees and vulnerable infrastructure[11].

A warmer climate multiplies the risk from these events in the future by expanding the peak season for extreme events and expanding the area where they can occur toward the north. Winter storms might be expected to be less likely due to warmer temperatures, but the increase in the strength of the water cycle could make them produce more snow or ice, causing problems for farmers worried about the transportation of milk from farms to dairies and cutting off electricity needed for milking or power. Even if the frequency of the storms does not change, the increased use of sophisticated technology could make them more vulnerable to extreme weather in the future. Recent events such as the cold outbreak in the central United States last week have shown us that we are not even able to respond adequately to weather and climate extremes similar to ones we know have happened in the past; responding to the more variable and more extreme weather that we expect to see in the future as shown by climate models will be even more costly, disruptive, and challenging.

How Climate Change is Impacting Agriculture and Forestry

Changes that we are seeing in our climate now are affecting agriculture and forestry in many ways. Rising temperatures are leading to warmer days and even warmer nights, which reduce heating costs in winter but increase cooling costs in summer. It also increases heat stress on both livestock and outdoor workers who are exposed to those high temperatures. Warmer overnight temperatures also harm some crops such as corn. The higher temperatures also lead to longer growing seasons, which Knox and Griffin (2014) estimated at roughly a one-week increase in the growing season for every 1-degree F rise in temperature.[12] The longer growing seasons provide opportunities for growing new crops and double-

[9] https://www.gfdl.noaa.gov/global-warming-and-hurricanes/
[10] https://blogs.ei.columbia.edu/2016/12/01/increasing-tornado-outbreaks-is-climate-change-responsible/
[11] https://www.spc.noaa.gov/misc/AbtDerechos/derechofacts.htm
[12] P. Knox and M. Griffin, Using Analog Methods to Illustrate Possible Climate Change for Agricultural Producers, https://ams.confex.com/ams/94Annual/webprogram/Paper232055.html.

cropping but also lead to longer seasons for pests and diseases that affect the crops, forests, and animals. Warmer temperatures are also shifting climate zones to the north, changing the mix of crops and tree species that can be grown in any area or what times of year they can be grown successfully. The exact amount of temperature change that will occur cannot be predicted because there are so many unknowns to consider, including what choices humans make about greenhouse gas emissions in the future, but a range of increases from roughly 4 to 9 degrees F is projected to occur by 2100 by most climate models, depending on the scenario chosen[13]. These changes will not be uniform across the globe; some areas may see greater temperature rises than others, but all areas will be affected.

More variations in the water cycle provide both positive and negative impacts on agriculture. Northern parts of the United States are benefiting from more rainfall and a longer growing season now versus early in the 20th century. Crops such as corn are expanding into areas that previously could grow only wheat, for example. But the increase in the heaviest rain is leading to more erosion and flooding, both of which hurt farmers who are concerned with soil health and transportation of products to market. In dry years, longer intervals between rain events puts extra stress on crops and forests, especially where the water-holding capacity of soils is low. In the western United States, warmer temperatures have caused more precipitation to fall as rain and less as snow, which significantly affects the availability of irrigation water for crops as well as city water supplies because there is less storage of water in mountain snowpacks. Droughts are also expected to become more frequent and longer in a warmer world because the higher temperatures increase evaporation from soil, streams, and lakes, and increase evapotranspiration from plants. Even if the total amount of precipitation does not change, more evapotranspiration will lead to higher water demands by crops and more evaporation from lakes and reservoirs will make water shortages more frequent. Increases in heat spells are also expected to lead to more rapid onset of droughts and more frequent flash droughts that primarily affect crops and increase the occurrence of forest fires in the western United States.

The increase in carbon dioxide (CO_2) in the atmosphere is expected to have some fertilization effect on plants, since they take in CO_2 as they grow. However, that effect is limited by the plant's ability to use the CO_2 and the availability of other required elements, including water and nutrients. Scientists have also noted that some weeds grow much more quickly in enhanced CO_2 environments than crops do. That could lead to more competition between crops and weeds, resulting in an increased need for herbicides, so the benefits from increased carbon dioxide are limited.

In recent years we have had many examples of the devastation that extreme weather can have on agriculture and forestry. Hurricane Florence (September 2018) caused tremendous damage to the coastal Carolinas, primarily due to flooding from rains of up to 36 inches in Elizabethtown, North Carolina[14]. The widespread flooding due to the slow-moving storm caused tremendous damage to sweet potatoes and other crops in eastern North Carolina and also caused the deaths of 3.4 million chickens and turkeys and 5,500 hogs. Hurricane Michael (October 2018) intensified just before landfall, bringing devastating winds through an area stretching from the Florida Panhandle to the northeast through southern Georgia and on into the Carolinas and Virginia. It was still a hurricane as it passed through central Georgia on October

[13] National Climate Assessment, 2018, https://nca2018.globalchange.gov/chapter/2/

[14] S. R. Stewart and R. Berg, National Hurricane Center Tropical Cyclone Report on Hurricane Florence, May 30, 2019, https://www.nhc.noaa.gov/data/tcr/AL062018_Florence.pdf

10, and the UGA Weather Station in Donalsonville in far southwestern Georgia reported a wind gust of 115 mph as the eyewall passed over the airport location. Losses to agriculture and forestry in Georgia and Florida were estimated at over $3.3 billion[15]. The storm hit about a week before most cotton was expected to be harvested, completely shredding many fields; it also flattened pine plantations and pecan groves that had been in farm families for generations, leading to years of losses of income for those families as they tried to reestablish their groves by planting new trees. Storms like the 2020 Midwestern Derecho also show the vulnerability of agriculture and forestry to severe thunderstorms and extreme weather, although it has not yet been determined whether these storms will become more frequent in the future[16].

How Agriculture and Forestry Are Impacting Climate Change

The growth of agriculture and forestry over time have resulted in many benefits to our citizens, including better access to food, fiber, and building materials. But agriculture and forestry have had negative impacts on our citizens and our climate as well. Food waste due to inefficient use of farm production and citizen consumption results in 30-40 percent of food being thrown away in the United States[17], even though many lower-income families do not have adequate access to the food they need. This leads to increased emissions of methane from landfills where the food is dumped. It also wastes the fertilizer, fuel, and water that was used to produce that food in the first place and the time and energy of people that are involved in producing and transporting that food from farm to market. Using too much fertilizer also results in the release of nitrous oxide, another greenhouse gas, which further increases global temperatures.

Livestock production allows ranchers and farmers to raise high-quality protein on land that often cannot be used for other economic activities. However, methane emissions from cattle produce 14 percent of greenhouse gas (GHG) emissions globally per year, although it is only 4 percent of all GHG emissions in the United States[18]. A lot of agricultural production goes towards providing the feed these animals use, and that production also emits greenhouse gases through the use of diesel fuel, fertilizers, and changes in land use from wetlands to cultivated crops.

Overuse of fertilizer, especially in areas with frequent heavy rains, causes problems with toxic water both locally, in rivers downstream from the fertilized fields, and in the Gulf of Mexico and ocean estuaries. This affects the livelihood of fishermen there by reducing the catch of commercial species as well as harming local ecosystems. It also reduces the health of the stream and estuary ecosystems and can lead to higher costs to treat the water for human and animal consumption and industrial uses.

Overall, the inefficient use of water and fertilizer and waste of food leads to serious economic consequences for agricultural producers, since they are the ones who pay for the diesel fuel to run equipment and pumps, and the chemicals needed to fertilize their crops and protect from weeds, pests, and diseases. Methods to make farms more efficient are often costly and put an extra burden on lower-

[15] J. L. Beven, R. Berg, and A. Hagen, National Hurricane Center Tropical Cyclone Report on Hurricane Michael, May 17, 2019, https://www.nhc.noaa.gov/data/tcr/AL142018_Michael.pdf
[16] https://www.spc.noaa.gov/misc/AbtDerechos/derechofacts.htm#climatechange
[17] https://www.usda.gov/foodlossandwaste/why
[18] https://www.ucdavis.edu/food/news/making-cattle-more-sustainable/

income and minority farmers who cannot afford the cost of the added enhancements, leading to reduced production and even less money coming in.

How Agriculture and Forestry Can Reduce Emission of Greenhouse Gases

Agriculture and forestry have a large role to play in reducing the effects of greenhouse gases. The best way to reduce greenhouse gases in the atmosphere is to prevent their emission in the first place. Then there is no need to remove them from the atmosphere later. In 2018, agriculture produced 9.9 percent of the U. S. emissions of greenhouse gases by economic sector[19]. Worldwide, agricultural emissions account for 24 percent of all greenhouse gas emissions. These emissions come from numerous sources, including livestock production, release from agricultural soils, and rice production.

There are many ways that agriculture and forestry can help reduce the output of greenhouse gases. One of the biggest potential new ways to reduce emission of these gases is through reduction of food waste and packaging, which reduces methane emission from landfills where the unused food is buried and also reduces the amount of fuel, fertilizer, and transportation costs used to produce the food that is not used. It also reduces the amount of land that needs to be cleared for new crops. Improved diets for livestock and anaerobic digesters to recover methane from animal waste can reduce the amount of methane emitted. Using soil-preserving methods such as growing cover crops helps keep carbon, nutrients, and water in the soil, reducing the need for fertilizers and running diesel-powered irrigation pumps. Making production more efficient by using tools like smart irrigation and better management of nitrate fertilizers also reduces the emission of greenhouse gases. The use of solar- and wind-powered pumps, where feasible, can also help cut the costs of fuel. Using new methods of cultivating rice using less water-intensive methods may also help to decrease methane emissions. Changing diets to eat lower on the food chain can also help reduce emissions.

Farming and forestry can also help by removing carbon dioxide and other greenhouse gases from the atmosphere. Growing forests and improving cropland productivity both pull carbon dioxide from the air as "carbon sinks." Many of the methods that reduce emission of these gases also help make the land better at removing carbon dioxide. For example, using no-till methods of farming keeps more water and nutrients in the soil and increases the health of the soil and of the plants in those fields, allowing them to suck up more carbon dioxide. Protection of existing forests and planting of new trees can also help to remove carbon dioxide from the atmosphere and cool the local climate. These practices also have other benefits such as protection of biodiversity, erosion control, and ecotourism, all of which can also benefit farmers.

Many of these solutions can be implemented now and many farmers are already doing so. For example, the number of cover crop acres in the United States increased by 5 million acres from 2012 to 2017, according to the 2017 Census of Agriculture[20]. There is also ongoing research funded by USDA and other agencies into how to make these practices even better and easier for producers to implement. Because there are so many different types of agricultural production, there is no "one size fits all" solution. Many of these newer methods of production will result in economic savings for the producers immediately without large capital outlays. This is particularly important for lower-income and minority farmers and

[19] https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

[20] https://www.farmprogress.com/cover-crops/census-finds-cover-crop-acreage-increases-50-nationwide

will be valuable to producers regardless of how the climate changes because the newer methods reduce the use of costly fertilizers, fuel for field work and irrigation, and other expensive inputs.

How Agriculture and Forestry Can and Are Adapting to Changing Climate

Since the climate is already changing and will continue to change for the foreseeable future based on greenhouse gases that have already entered the atmosphere or will be emitted in the future, farmers will also have to adapt to warmer temperatures, longer growing seasons, and more variable rainfall. In fact, many farmers have already started to take advantage of these changes. A longer growing season can lead to the enhanced ability to produce two crops instead of one ("double-cropping"), or to choose different varieties with higher yield that take longer to grow. That allows producers to diversify and create multiple income streams from the different crops they grow. Farmers are also experimenting with new crops that expand their options for selling locally at premium prices. For example, in Georgia producers are now starting to grow satsuma mandarins in the southern parts of the state, and olive groves and pomegranates have also been introduced to expand market options. In the northern part of the United States, some areas that are seeing increased rainfall are now growing corn where it was not previously possible due to the dry conditions. Expansion of other crops towards the north may also occur where appropriate soils and rainfall permit them to grow. However, more research is needed on whether the changes in climate that are occurring are compatible with how those crops grow.

Livestock producers are also adapting to a warmer climate by protecting their animals from heat stress using shade structures, or in some cases, keeping their dairy herds in air-cooled barns. New breeds like White Angus have been introduced to see if they can withstand high levels of heat stress better than current breeds. New hybrids of commercial crops and fruit such as peaches, which need a certain amount of cold weather to produce good yields, are being developed to grow in the new, warmer conditions. Foresters are also testing out different species of pine and other commercial varieties of trees to make sure that those forests will thrive under the climate conditions that are expected to occur as those trees mature. Many of these approaches require research to learn how to make the best choices, but farmers are already taking the lead on testing new varieties and new crops to determine their market values and growth patterns.

What USDA and other agencies are already doing to prepare for changes in climate and extreme weather

The USDA has a long history of providing science-based, region-specific information and technologies to agricultural and natural resource managers across the United States, both alone and with other federal and state agencies. This information helps land managers to make better choices based on scientific principles. The USDA also provides decision tools and guidance on how to use them so farmers from a wide range of backgrounds can use them effectively. In 2013, the USDA Climate Hubs were chartered to "provide a link between research activities and practical, actionable information that producers can use to make climate-smart management decisions[21]". They are led by Agricultural Research Service and Forest Service senior Directors with contributions from many other programs including the Natural Resources Conservation Service, Farm Service Agency, Animal and Plant Health Inspection Service, and the Risk Management Agency. The hubs currently address how working lands can be managed to become more

[21] https://www.climatehubs.usda.gov/about-us

resilient to extreme weather including hurricanes, wildfires, floods, and droughts. For example, the Southeast Regional Climate Hub has produced a series of crop-specific hurricane preparedness and recovery guides[22] that are being used to help producers plan for how to deal with hurricanes, which have severely impacted agriculture in the Southeast over the last five years. They also provide advice for what to do after a hurricane moves through the region. Other hubs provide information on dealing with drought and other types of extreme weather and climate that affect many different types of agricultural production. As an Extension specialist I use the information from all these sources to help producers make more informed choices about what crops to grow and how to manage them based on the current climate and what is predicted in the future.

Other programs within USDA provide financial support for scientists who are looking for better solutions to problems related to extreme weather and climate change. I have benefited from several grants from the National Institute of Food and Agriculture (NIFA), including one to put together training materials for extension agents and producers on livestock and climate across the United States and another looking at the impacts of drought and a warming climate on crop production in the Southeast. Other initiatives have focused on forestry and tools to help foresters pick the tree varieties that will do best in the future climate. USDA is currently providing funds for a project that I am co-Principal Investigator on that studies the impacts of "flash" drought. We are evaluating a variety of low-cost sensors that can be used by farmers in the Southeast to make water-smart decisions which will target efficient water use. This will also reduce fuel use and decrease the amount of fertilizer runoff into streams and, eventually, the ocean by using water wisely only when and where it is needed.

In addition to USDA, there are many other federal agencies working in the area of monitoring climate and preparing for and responding to weather extremes as well as preparing for future impacts. One of these groups is NASA; you will hear more about their activities from one of the other experts in this panel. The agency that I work with most often is the National Oceanic and Atmospheric Administration (NOAA), which provides information on real-time weather and climate conditions across the U.S. and the world. NOAA scientists and employees also work with many constituent groups on when to expect extreme weather conditions. They also work with emergency managers to prepare for extreme events as well as study extreme weather and climate events from the past to learn better ways to respond to them next time.

In addition to federal agencies, there are many state and local agencies and private organizations that are also working in the area of agriculture, forestry, and climate change. I am proud to be an Extension specialist at the University of Georgia. Surveys of farmers show that nearly half (47.8%) of farmers surveyed in a recent study found university Extension to be the most trustworthy source of climate change information[23]. Extension agents serve a critical role in translating the science of climate variability and change into actionable decisions that local farmers can use to improve crop yields today and prepare for variations in climate in the future. We work with both academic and industry scientists and farmers, including those from both large and small farms, to identify developing critical conditions that may affect their crops and to help them plan for future impactful events.

[22] https://www.climatehubs.usda.gov/hubs/southeast/topic/hurricane-preparation-and-recovery-southeast-us
[23] Journal of Extension, https://www.joe.org/joe/2018june/a7.php

Cooperative efforts between these groups have already produced important information about the relationship between agriculture and climate. The *Fourth National Climate Assessment*[24] includes an entire chapter on Agriculture and Rural Communities that addresses many of the issues I have mentioned above and relates it to rural communities and the economies there, which are mainly driven by agriculture. USDA also released a new publication, *Climate Indicators for Agriculture*, which describes how changing climate is affecting agricultural indicators such as chill hours, growing degree days, extreme rainfall, and heat stress[25].

Recommendations to enhance efforts to assist agricultural producers respond to climate change

Based on the climate changes that have already occurred and will continue to change in the future, there are many ways that Congress can act to assist producers in both adapting to the ongoing changes and reducing the emission and concentration of greenhouse gases in the atmosphere. In general, Congress can encourage the use of research incentives to scientists to produce more targeted and applied ways of doing smart agriculture. This should not be done in a vacuum but should be done through collaboration with farmers using the expertise and assistance of Cooperative Extension and other groups that work at the intersection between science and production.

To facilitate the use of smart agriculture, farmers should be equipped with improved access to resources like the internet so they can access tools and information that relate climate to agriculture and forestry. This will help farmers improve their farm and woodlot management choices and show them how to use the information effectively. Congress can also encourage access to needed agriculture-specific data such as the agricultural weather networks ("mesonets") that are already in place in some states and encourage their expansion to other agricultural areas that have fewer resources. This will help producers make effective decisions which will conserve resources and save money. This information should also be shared with other countries because improvements in agricultural production and better capture of carbon using water, fuel, and agricultural chemicals more efficiently will benefit the global climate system far more than just doing it in the United States alone.

In conclusion, I would like to highlight the following four points:

1. ***The time to act is now.***
   Reducing greenhouse gas emissions and responding to the changing climate is not something that can wait until we have perfect answers. We will never have perfect knowledge since science is constantly making new discoveries and farmers are innovating their own production methods at the same time. If we wait, we will waste time while we put more greenhouse gases into the air that will require removal. The climate will get more extreme as a result of those additional gases. It's better not to emit the greenhouse gases in the first place. As our mothers reminded us, an ounce of prevention is worth a pound of cure. The longer we wait, the more unpredictable and extreme the climate is likely to become. Technology is always changing, and we can and must

[24] 4th National Climate Assessment, 2018, chapter on agriculture, https://nca2018.globalchange.gov/chapter/10/
[25] Climate Indicators for Agriculture, https://www.usda.gov/sites/default/files/documents/climate_indicators_for_agriculture.pdf

incorporate those changes into our management plans in the future, but we can take concrete steps now that will also save farmers money by reducing the costs of production. You can think of this as a ship captain responding to the sight of an iceberg ahead. If we respond to it now, we can make smaller, less drastic changes that will keep the ship safe, while if we wait, much more wrenching changes will be needed the closer we get to the iceberg in the future.

2. ***Economically, many farmers will benefit from these activities regardless of how the climate is changing.***

Conserving water, fuel, and agricultural chemicals like fertilizer and herbicides makes good financial sense for farmers. Improving the health of the soils on farms, rangelands, and in forests will provide additional benefits to producers like better fertility and water-holding capacity, making them more resilient to extreme climate events like drought. It is especially true for producers who own the land rather than renting it, because they receive more tangible economic benefits from improving the soil, since they may be able to use less water and fertilizer over time. This is especially important for producers who want to keep the farms in their families over many generations, because they need to maintain the soil's health over many years of production as well as minimize production costs to keep more money on the farm. Climate-smart and sustainable agriculture also benefits local water supplies, municipalities, and ecosystems because resources are not being wasted or degraded.

Note that not every solution will work for every producer. Farm size, type of crop or crops, availability of money to use on farm equipment, and expertise all vary widely across the U.S. The use of irrigation to reduce vulnerability to drought may help some commodity farmers but be too expensive for small farmers unless simpler, lower-cost alternatives are developed and encouraged. In some parts of the country, like the Southeast, we usually have enough water for crops compared to other parts of the United States, but it sometimes needs to be supplemented to provide a boost to crops during a hot, dry spell. This water often only needs to be moved short distances to keep the crops growing and requires the use of much smaller infrastructure than the big irrigation projects out West that move water long distances to get it to the crops that need it. By working with scientists and producers to find the best ways to keep their crops alive in a cost-effective way, the farmers will be able to respond to the climate variations we are seeing now as well as adapt to and become more resilient to future climate change. This is especially important because climate models have a harder time predicting what the future precipitation patterns will be than they do temperature patterns, and so flexibility in how farmers adapt is particularly important. These low-cost, local solutions will especially benefit Black and small-scale farmers because they will allow crops to survive with lower costs than some bigger water projects, although those also have a place in some parts of the country.

3. ***Good management requires good data and useful tools.***

The best-managed farms use data to monitor their production and determine where and when to apply water and agricultural chemicals and decide when to harvest. Good data can also tell them when their livestock are under stress and use appropriate measures to keep them healthy. Tools such as smart irrigation schedulers and precision agriculture can cut costs and reduce the waste of fuel, water, and fertilizer by allowing producers to apply the right amount at the right time to

maximize benefits to the crops without overusing them. In the future, agriculture will become even more technologically advanced. Use of machine learning and artificial intelligence will require good input data, the availability of computers and internet access, and access to equipment that can take advantage of this knowledge.

Traditional sources of weather data such as the National Weather Service collect information that is useful for farmers, but stations are widely separated and often do not capture measurements that are agriculturally important such as soil temperature, soil moisture and solar radiation. This is where supplemental weather observations from individual stations and networks of agricultural stations in mesonets can be of tremendous importance. The House has already recognized the importance of these mesonets in the NOAA pilot program enacted under section 511 of the Water Resources Development Act, which was included in the FY21 Appropriations package. Mesonets like the one that I manage at the University of Georgia provided tremendous added value to agricultural producers by increasing the density of observations, especially in rural areas where traditional weather observations are rare. They also provide data that cannot be obtained from more traditional sources. Production tools based on these data, such as irrigation schedulers, warning systems for development of critical pests and diseases, and trackers of crop development stages can provide highly useful and important information that farmers can use to minimize expenses and maximize yield.

To access weather and climate information and use tools effectively, farmers must have access to both the weather data and to the tools that use the data to make crop predictions. That is especially difficult in rural areas where access to the internet is limited, especially by low-income and Black farmers. To make maximum use of this information, rural broadband access must be improved. New agricultural tools need to be identified by scientists working together with producers to make sure that they are useful, reliable, and easy to use. Farmers must also learn how to use these tools effectively so that they can apply them to their management practices. Extension and the climate hubs have an important role to play in making sure this information is useful and is reaching the farmers who need it. Use of the data along with the agricultural tools that use them provide both short-term economic benefits to farmers by reducing wasted money, fuel, and labor as well as long-term benefits by reducing emission of greenhouse gases.

4. ***Farmers and foresters must be an integral part of the process.***
No one knows better how to farm than the farmers themselves. Innovation in farming has improved productivity dramatically over time, and farmers will continue to work to improve efficiency and manage crops better and more economically. But farmers and foresters must work with scientists to make sure they are not just doing what they have always done before, if there is something better based on science. They also need to know what the future weather and climate risks to farming and forestry are so that they manage their land appropriately. Scientists have the expertise to test new innovations carefully and demonstrate which ones are the most economical and beneficial. But scientists need to work with producers to make sure that the innovations are also practical and cost-effective and address the issues that farmers have to deal with on a daily basis.

The USDA Climate Hubs along with other federal climate centers have an important role to play in both developing new tools and information sources for producers and in telling the farmers and foresters how to use these products effectively. This can be done through publications, web resources, and workshops, but they need to incorporate the input of practicing farmers and foresters as well as scientists. Extension also has an important role to play in this process, since extension agents work in the fields with farmers and see first-hand what problems the farmers are facing and how available information is used as well as what is missing. By serving as a liaison between the scientists and the producers, extension agents bring together academic and practical experience which will produce the most effective solutions for agricultural systems responding to both climate variations like drought and extreme weather like hurricanes, forest fires, and floods, both now and in the future. That way scientists and farmers and foresters can work together to help solve the problem of climate change in a way that benefits us all.

Thank you again for the opportunity to provide you with this look at the relationship between agriculture and forestry and climate change in the United States. I look forward to hearing your comments and answering your questions on this topic.