HOTTER FIELDS
LOWER YIELDS

How Global Warming Could Hurt America's Farms

ENVIRONMENT VIRGINIA

Hotter Fields, Lower Yields

How Global Warming Could Hurt America's Farms

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Table of Contents

Executive Summary

America's reliance on fossil fuels – coal, oil, and natural gas – is fueling global warming and causing a host of other environmental, economic, and security problems. And while the impacts vary from region to region, global warming threatens all sectors of our economy, and agriculture is no exception.

Not all the effects of global warming will be bad for agriculture; growing seasons will be longer, and increased carbon dioxide levels encourage plant growth. But global warming will make some of the challenges that agriculture faces significantly worse, including increasing temperatures, more damaging storms, ozone pollution, and spreading pests, weeds, and diseases.

This report examines the impact of global warming on corn, America's largest crop, which is particularly vulnerable to productivity losses from the higher temperatures expected from global warming.

Climate changes since 1981 have already cost corn growers worldwide about $1.2 billion per year.[1] A recent study by Lawrence Berkeley National Laboratory and the Carnegie Institution found that combined changes in temperature and precipitation since 1981 resulted in lower yields in corn and other crops, leading to wasted productivity and lost revenue. Unfortunately, these trends in climatic changes are only expected to worsen unless global warming pollution declines substantially in coming years.

Based on a recent U.S. government assessment, this report estimates that global warming will cost corn growers in the United States at least another $1.4 billion per year in the future, as temperatures increase. (See Figure 1 for the estimated cost to each state.) A recent report by the U.S. Climate Change Science Program, a collaboration of the U.S. Department of Agriculture and 12 other federal agencies, estimated that an additional increase in temperature of 2° F and in carbon dioxide of 60 parts per million would have opposing effects on corn yield. Overall, corn yields in the Midwest and South would decrease by an estimated 3 percent relative to a world without global warming.[2] At today's production levels and prices, the productivity loss would cost the 10 most vulnerable states an average of $116 million a year.

Destructive storms, pests, weeds, diseases, and ozone pollution will result in further damages to corn and agriculture from global warming. The losses above only represent the negative effects of higher temperatures and the positive effect of higher carbon dioxide levels, and they assume an adequate water supply for each crop. More and more rain is expected to fall during intense storms, saturating soils, increasing the risk of floods, and making it harder for plants and soils to absorb water before it washes into streams and rivers. Crop nuisances, such as insect pests, weeds, and diseases, will have greater range and reproductive speed with increased temperatures. And ozone pollution, from which rural parts of the Midwest and East suffer more than almost anywhere else on Earth, is toxic to plants and is expected to become more concentrated with the increased temperatures of global warming.[3]

Agriculture can help reduce further damage from global warming and spur the transition to a clean energy economy. Clean energy resources, such as wind

Figure 1. Projected Yearly Damages to Corn Production Due to Global Warming by State

STATE	LOSSES (millions)	STATE	LOSSES (millions)
Iowa	$259	Arkansas	$8.7
Illinois	$243	Maryland	$6.2
Nebraska	$163	Georgia	$6.0
Minnesota	$135	Oklahoma	$5.0
Indiana	$98	Virginia	$5.0
South Dakota	$63	California	$4.7
Kansas	$62	Alabama	$3.9
Ohio	$50	South Carolina	$2.9
Missouri	$46	Delaware	$2.5
Wisconsin	$41	Washington	$2.3
Texas	$37	Idaho	$1.8
North Dakota	$33	New Mexico	$1.7
Michigan	$32	New Jersey	$1.1
Kentucky	$19	Wyoming	$0.8
Colorado	$18	Oregon	$0.8
Mississippi	$14	Montana	$0.6
Pennsylvania	$13	Florida	$0.5
New York	$12	West Virginia	$0.4
Tennessee	$10	Utah	$0.4
Louisiana	$9.8	Arizona	$0.4
North Carolina	$9.3	**United States total**	**$1.4 billion**

Note: Alaska, Connecticut, Hawaii, Maine, Massachusetts, Nevada, New Hampshire, and Rhode Island have negligible corn industries.

turbines, solar panels, and environmentally sustainable biomass, can provide farmers an independent source of power and income while reducing global warming pollution. By investing in these and other clean energy solutions, we can help stop global warming and boost the agricultural economy.

Improved farming practices can reduce global warming emissions and keep more carbon in soils, and a well-designed global warming program could reward farmers for such improvements. Farmers could receive incentives through a dedicated climate fund established by Congress. The revenue for the fund would come from the payments energy companies make to purchase pollution permits and would represent a relatively small percentage of the overall revenue collected by the government from such permits. Importantly, emission reductions resulting from such a dedicated fund would be *in addition* to the reductions required by power plants and other sources regulated under the program.

Decision-makers should unleash clean energy to help rebuild America's economy and stop the worst effects of global warming. Specifically, decision-makers should:

- Establish science-based pollution targets to reduce total U.S. global warming emissions by at least 35 percent below today's levels by 2020 and 80 percent by 2050, and require the targets to be periodically updated as science evolves;
- Auction all of the pollution allowances and devote all of the proceeds to helping the nation use energy more efficiently, shifting to renewable energy, providing incentives to America's farmers, and addressing impacts on consumers – particularly those with low- and moderate-incomes, workers, vulnerable communities, and natural resources;
- Strictly limit and ensure strong rules for carbon offsets so that our efforts to reduce pollution are effective;
- Require utilities to obtain at least 25 percent of their electricity from renewable sources by 2025 and to reduce their energy use by 15 percent by 2020; and
- Cut energy use in new buildings in half by 2020 on the path toward zero energy by 2030.

Introduction

Global warming headlines often feature rising sea levels and record temperatures. But the ravages of global warming won't stop at our coasts, and the impacts of higher temperatures won't be limited to areas where heat waves are more hazardous than blizzards. Rather, scientists looking at a future in which we continue to depend on fossil fuels for energy predict dramatic changes to all regions of the world and every sector of society.

American agriculture is no exception. While a longer growing season and higher concentrations of carbon dioxide can benefit some crops, hotter summers, more damaging storms, ozone pollution, and spreading pests, weeds, and diseases will take their toll.

In fact, increases in temperature linked to global warming are already damaging crops worldwide. One analysis discussed in this report found that production of corn, wheat, rice, barley, and sorghum are less than what they could have been were it not for climate-driven changes in the last few decades. Of the crops studied, soybeans were the only crop not already suffering from global warming.[4] Climate changes are already happening and indeed are occurring more quickly than the world's scientists predicted just two years ago.[5]

In this report, corn, America's largest harvest, serves as a bellwether for potential problems to agriculture from global warming. But it is important to remember that these changes don't represent the only possible future. If we reduce global warming pollution quickly and deeply and sequester more carbon in our plants and soils, we can still avoid the worst consequences of global warming.

As President Obama said, "The time to take charge of our future is here."[6]

Global Warming and Agriculture

Higher Temperatures

Human activities, such as burning fossil fuels, are the primary cause of global warming.

Global warming is caused by human exacerbation of the greenhouse effect. The greenhouse effect is a natural phenomenon in which gases in the earth's atmosphere, including water vapor and carbon dioxide, absorb infrared radiation emitted from the earth's surface. The process prevents energy from escaping into space, thus keeping the earth warm. The greenhouse effect is necessary for the survival of life; without it, temperatures on earth would be too cold for humans and other life forms to survive.

Humans, however, have altered the composition of the atmosphere in ways that unnaturally intensify the greenhouse effect. Primarily by burning fossil fuels, humans have increased the levels of greenhouse pollutants in the atmosphere—especially in the period since the Industrial Revolution.

The upward pressure on temperature can already be seen across the globe; average surface temperatures have increased by more than 1.4°F since the mid-19th century.[7] Globally, the 10 warmest years on record have all occurred in the last 12 years.[8]

In 2007, the United Nations' Intergovernmental Panel on Climate Change concluded that the evidence of global warming is "unequivocal" and that human activities are responsible for most of this rise in temperature.[9] So far this decade, emissions, warming, and impacts have all been at the upper end of IPCC projections.[10]

Changing Weather Patterns

Rising temperatures are not the only effect global warming has on climate. The increased surface, air, and ocean temperatures have many secondary effects on weather patterns around the globe. Global warming's impact on climate varies from location to location and can sometimes have counter-intuitive effects, such as more lake-effect snow in the Great Lakes region.[11] Many of the most dangerous weather events, such as storms with extreme precipitation and hurricanes, are expected to become even bigger problems if global warming pollution continues to increase.

More Destructive Storms

There is broad scientific agreement that global warming will lead to more frequent and more destructive extreme weather events, including storms with heavy rainfall. We are already seeing these effects across the globe, including in the United States.[12] Extreme weather events can damage crops and livestock as well as buildings, bridges, and other infrastructure important to agriculture.

EXTREME PRECIPITATION AND FLOODS

Scientists expect global warming to increase the frequency and intensity of the storms with the most precipitation, which raises the risk of damaging floods. Over the last 60 years, storms with extreme precipitation have increased 24 percent, and Americans now spend $2.9 billion on flood insurance each year.[13]

TORNADOES

The United States, and especially the Midwest and East, are already home to most of the world's tornadoes.[14] Tornadoes are expected to become more common as temperature increases make the storms that create them more likely.[15]

HURRICANES

Warmer surface temperatures in the ocean are expected to make hurricanes even more intense. In 2008, the United States Climate Change Science Program found that every 1.8 °F increase in temperature would increase hurricane wind speeds by between 1 and 8 percent and rainfall by between 6 and 18 percent.[16]

Wider Range of Pests, Weeds, and Diseases

Expansion of pests, weeds, and crop diseases will occur from the changes brought by global warming, such as increases in temperature, carbon dioxide, humidity, and rainfall.

RANGE EXPANSION

Temperature is the main determining factor for the reach of most weed and pest species. Therefore, temperature increases due to global warming will likely result in weed and pest ranges expanding to the traditionally cooler climates in the north.[17] For example, earlier appearances and changes in the geographic ranges of many insect species are already being observed in Western Europe due to global warming.[18]

INCREASED PESTICIDE COSTS

Pest populations expanding their range northward due to global warming is not only bad for crops but also can chip away at farmers' bottom lines. In the United States, the data clearly show more frequent use of pesticide sprays in warmer climates. In Florida, for example, farmers on average spray for pests in sweet corn 15 to 32 times a year, whereas farmers in Delaware on average spray four to eight times a year.[19] Farmers in New York on average spray even less frequently, zero to five times a year.[20] If warming occurs as projected and the ranges of pest species expand northward, farmers in northern states may be inclined to spray more, at higher financial and environmental cost.

WEED GROWTH

Changes from global warming will make weeds a bigger problem for agriculture for several reasons. First, increasing temperatures from global warming will likely have a substantial effect on the range expansion and growth of weed species.[21] Second, studies show that increases in carbon dioxide foster invasive weed growth more than most cash crops such as corn, giving them an edge when competing for sunlight and nutrients.[22] And while global warming encourages weed expansion, increased carbon dioxide levels may also make them harder to kill. Glyphosate (commonly used as *Roundup*), the most widely used herbicide in the country, may be less effective on weeds grown in conditions with higher levels of carbon dioxide.[23]

DISEASE PROLIFERATION

Crop diseases, specifically some leaf and root pathogens, respond well to humidity increases and higher frequencies of heavy rain events. These factors and rising temperatures will likely result from global warming over the next few decades and will increase the occurrence and spread of such pathogens in plant species.[24] Diseases can affect corn growth and quality, further damaging production.

Increased Local Air Pollution

Over the past 50 years, levels of ground level ozone have increased in rural areas of the United States and are projected to continue increasing over the next 50 years, due in part to global warming.[25] Studies show that ozone is toxic to many plant species, especially soybeans, wheat, peanuts, and cotton.[26]

There is wide scientific agreement that ozone levels are already damaging production of many crops, and this impact is only expected to become a bigger problem as ozone levels increase according to government projections. Research with soybean crops showed a 25 percent reduction in yields with elevated ozone levels.[27]

Studies show that rural areas in the Midwest and Eastern United States have some of the highest rural ozone levels in the world.[28] As rural U.S. ozone levels increase, there could be negative impacts on the competitiveness of the U.S. corn crop in the global market in coming decades.[29]

Global Warming Will Hurt Corn Production

Corn is the canary in the coal mine for the potential impacts of global warming on agriculture. Relative to a world without global warming, yields have already suffered worldwide from increased temperatures and precipitation linked with global warming, and damages are expected to increase despite small benefits from carbon dioxide (CO_2) levels.

Corn Likes it Cool

Corn's ideal temperature range for maximum yield is about 64 – 72° F.[30] Above that range, higher temperature shortens the reproductive life-cycle of the plants, giving the grain less time to grow and decreasing yield. A study by the University of Florida and others measured corn growth in several parts of the United States and Australia and found that Grand Junction, Colorado produced the most corn per acre.[31] The fields, nearly a mile high amongst the Rocky Mountains, maintain a cool temperature throughout the growing season, which the researchers concluded was the best setting for corn growth.

Climate Changes Are Already Hurting Corn Production

As global warming increases temperatures, fields are becoming too hot to let corn reach its full production potential. A study by Lawrence Berkeley National Laboratory and Carnegie Institution found that climate changes since 1981 already cost corn producers worldwide about $1.2 billion per year.[32] The study divided the corn-growing world into small pieces to separately analyze the effects of many changing variables in corn production. After accounting for the effects of the non-weather related factors, the report found that overall, changes in temperature and precipitation since 1981 resulted in lower yields in corn and other crops and used the data to estimate lost production.

Findings

In this report, we evaluate the effects of climate on the production of corn, America's largest crop.[33] Studies have found damage to corn production from climate changes in the last few decades that are consistent with global warming, and scientists expect even greater damages in the future. We used data on effects of higher average temperatures and CO_2 levels on yield to estimate expected damages to each state.

In a 2008 report, the U.S. Climate Change Science Program, a collaboration of the U.S. Department of Agriculture and 12 other federal agencies, found that an additional increase in temperatures of about 2° F in the Midwest and South would decrease corn yields by about 4.0 percent relative to a world without global warming. Other studies predicted even greater losses.[34]

At the same time, higher carbon dioxide levels from continued emissions are expected to artificially spur plant growth, and the U.S. Climate Change Science Program report estimated that total plant growth would increase by 1.0 percent from a higher CO_2 concentration of 440 parts per million (ppm).

This increase in temperature and carbon dioxide concentration is well within the projections by the IPCC.[35]

The combined effect of this increase in temperature and CO_2 concentration, according to the U.S. Climate Change Science Program report, will result in an estimated yield loss of about 3.0 percent, assuming sufficient water supply. It is important to note that if global warming emissions continued unabated, conditions would continue to worsen, with dramatic crop failure for corn if temperatures reach about 95° F during pollination, which typically occurs for a couple weeks around July.

Figure 2. Projected Yearly Damages to Corn Production Due to Global Warming by State

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Pennsylvania	$13	Florida	$0.5
New York	$12	West Virginia	$0.4
Tennessee	$10	Utah	$0.4
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North Carolina	$9.3		

Note: Alaska, Connecticut, Hawaii, Maine, Massachusetts, Nevada, New Hampshire, and Rhode Island have negligible corn industries.

We used total 2008 revenues of the corn industry in each state to estimate the damage from increased temperature and CO_2 levels. For the United States as a whole, the corn industry was valued at $47 billion in 2008. With higher temperatures and CO_2 levels, future production will be about 3 percent less, costing the industry an estimated $1.4 billion. The results from all the states are in Figure 2, based on 2008 corn prices and production.

The Corn Belt has the most to lose from global warming impacts on corn, with Iowa leading the states in yearly damages of $259 million. The top 10 states averaged $116 million in yearly damages, and about 40 percent of states will encounter $10 million or more in losses annually.

Agriculture Can Help Solve Global Warming

While global warming is an enormous challenge, America's farmers can help reduce further damage from global warming and benefit from the transition to a clean energy economy.

Clean Energy on American Farms

Agriculture has several advantages in producing clean energy from sources such as wind and solar power. First, as a major landowner in the United States, the industry has access to wind and solar resources. Second, in many cases, farmers can take advantage of the energy resources with minimal impact on existing crop and animal production. Finally, for the purpose of electricity used on farms for buildings, machinery, and pumps, generating electricity locally improves the reliability of electricity flow. Below are a few clean energy solutions that are promising for America's farms.

WIND POWER

Wind power is the greatest clean energy source that has been utilized by enterprising farmers. Farmers typically earn $4,000 to $8,000 per year for each turbine installed on their land, and farmers can continue to plant crops and graze livestock right up to the base of the turbines.[36] A large turbine takes up less than half an acre of land, including access roads. That same amount of land would produce less than $200 of crops or less than $20 of livestock compared with the thousands of dollars of electricity it generates.[37]

SOLAR ENERGY

Using solar power to generate electricity for farm operations can also decrease global warming pollution while saving money and lowering the risk of a blackout. Remote locations are especially appropriate for solar electricity since panels avoid the need for fuel, moving parts, and transmission lines. In some cases, solar power is already the most cost effective power source for uses more than 50 feet away from existing power lines.[38] But solar power can also be used for other purposes on a farm, such as heat. One farmer in Switzerland, for example, added a black metal roof to his barn to collect the sun's energy and installed a fan to bring hot air from under the roof into the main room to dry hay. The setup saves him $4,100 a year in fuel and maintenance costs.[39]

Global Warming Pollution Reduction on American Farms

There are many opportunities for farmers to reduce global warming pollution, such as methane and nitrous oxide, and to increase the storage of carbon in soils.[40]

ENRICHING SOIL

Soil is the third largest store of carbon on the planet, and using farming practices that maintain more organic matter in soils, such as dead or living plant matter and microbes, can improve productivity while keeping more carbon dioxide out of the air. Soils that become depleted of naturally occurring organic matter from

cultivation sometimes use inorganic fertilizers to compensate for the loss of nutrients, which release nitrous oxide, another global warming pollutant. By enriching soils with organic matter, farmers can limit inorganic fertilizers and reduce nitrous oxide emissions while increasing the store of carbon in the soils.[41]

REDUCING METHANE FROM LIVESTOCK

Manure from livestock is a large source of methane, another global warming pollutant, but certain management techniques can reduce emissions or even use the methane to produce valuable energy. Feed supplements and other technologies, for example, can reduce the amount of methane produced during livestock feed digestion; reductions up to 20 percent have already been achieved.[42]

Alternatively, manure can be placed in a biogas digester, which is a controlled airtight container that uses microbes to break down the manure. The digester can turn the waste or other organic matter into gases that can be burned for energy and a low-odor sludge that can be used as fertilizer, reducing global warming pollution and creating useful product.[43] In Pennsylvania, Penn England Farm installed a biogas digester to reduce electricity costs and take advantage of other benefits such as controlling odor. The system processes manure for 800 cows and the resulting gas produces heat for water, buildings, and the biogas digester, and electricity for on-site operations and sales to the utility for 3.9 cents per kilowatt-hour. [44]

PRODUCING ENERGY FROM ENVIRONMENTALLY SUSTAINABLE BIOMASS

Organic matter such as waste agriculture material can also be used to produce energy. The chemical energy in organic material can be processed and burned to produce heat for water or buildings, or be used to generate electricity. Depending on the production and processing methods, however, it is possible for biomass energy to generate even more global warming pollution than fossil fuels. Biomass projects should be designed to reduce global warming and other pollution, relative to the alternatives.

Incentives to Fight Global Warming

Farmers could receive incentives to reduce global warming pollution and increase the storage of carbon in soils through a dedicated fund. The revenue for the fund would come from payments energy companies make to purchase pollution permits and would represent a small percentage of the overall revenue collected by the government from such permits. Importantly, emission reductions resulting from such a dedicated fund would be *in addition* to the reductions required by power plants and other sources regulated under the program.

For example, Representative Ed Markey, now the chair of the House Energy & Commerce Committee's Energy & Environment Subcommittee, introduced legislation last year to establish an Agriculture and Forestry Carbon Fund under the United States Department of Agriculture, which would have dedicated an estimated $378 billion through 2050 to support projects by American farmers and foresters. These projects would increase biological sequestration of carbon dioxide or reduce global warming emissions through improved agricultural soil management and forest management practices.

Conclusion

Corn, America's largest harvest, is the canary in the coal mine for productivity losses America's farmers could see from global warming. In the coming decades, American corn growers and other farmers will face increasing temperatures, more severe storms, spreading pests, and higher levels of air pollution. While global warming poses serious challenges, America's farms can be part of the solution.

To repower America with clean energy and stop the worst effects of global warming, including on America's farms, policymakers should:

- Establish science-based pollution targets to reduce total U.S. global warming emissions by at least 35 percent below today's levels by 2020 and 80 percent by 2050, and require the targets to be periodically updated as science evolves;
- Auction all of the pollution allowances and devote all of the proceeds to helping the nation use energy more efficiently, shifting to renewable energy, providing incentives to reduce global warming pollution on American farms, and addressing impacts on consumers – particularly those with low- and moderate-incomes, workers, vulnerable communities, and natural resources;
- Strictly limit and ensure strong rules for carbon offsets so that our efforts to reduce pollution are effective;
- Require utilities to obtain at least 25 percent of their electricity from renewable sources by 2025 and to reduce their energy use by 15 percent by 2020; and
- Cut energy use in new buildings in half by 2020 on the path toward zero energy by 2030.

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Environment Michigan Research & Policy Center
Environment Minnesota
Environment Nevada
Environment New Hampshire Research & Policy Center
Environment New Jersey Research & Policy Center
Environment New Mexico Research & Policy Center
Environment North Carolina Research & Policy Center
Environment Ohio Research & Policy Center
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