"The dual forces of population growth and climate change will exacerbate pressures on land use, water access, and food security."

Climate Change and Food Security

BRUCE A. MCCARL, MARIO A. FERNANDEZ, JASON P. H. JONES, MARTA WLODARZ

Of the 10 warmest years in recorded history, 9 have appeared in the past 10 years, and all since 1998. Furthermore, 2012, the 9th-warmest year in history, was the 36th year in a row above the twentieth century average. Simultaneously, precipitation patterns are changing, with rainfall generally becoming more concentrated. Not surprisingly, the effects on agriculture from such climate change are proving significant and worldwide, including in the United States. The US National Oceanic and Atmospheric Administration estimated, for instance, that climate change made a 2011 drought in the American Southwest 20 times more likely to occur.

RESOURCES

Global Trends, 2013

At the same time, the role of agriculture, a sector highly vulnerable to climate change, is changing globally. Not only does farming remain vital for food and fiber supplies; it is also growing in importance as a source of feedstock for energy production. It is frequently mentioned, too, as a possible source of offsets to the greenhouse gas emissions that contribute to global warming.

Climate trends, in short, raise critical questions for the future of agriculture. What influence is climate change having on agricultural yields? Does it imply that farming might be less able to supply future food needs, especially given the likely demands from a growing population and from populations with growing income? And what might nations do to lessen the disruptive influence of climate change on agriculture?

To help put these questions in perspective, it is worth mentioning a couple of climate change's fundamental characteristics. First, the preponderance of evidence indicates that it is likely to make conditions hotter and overall wetter, but with a more variable set of weather patterns. Second, climate change has not been observed to, nor is it projected to, have geographically uniform effects. In particular, while most every place is expected to be hotter with more variable conditions, some regions are likely to be drier while others will be wetter.

THE CULPRITS

A changing climate certainly alters agricultural productivity. Ultimately, conditions involving extreme heat or extreme cold, as well as extreme wetness or extreme dryness, are unsuitable for raising crops. Crops fare best within narrow temperature and precipitation bands. Fortunately, temperature and precipitation conditions vary geographically. Conditions near the poles are generally too cold, while those near the equator can be too hot. Not all crops need the same ranges: Wheat, for example, fares best under comparatively colder conditions, and cotton or rice under hotter ones, while corn and soybeans need moderate conditions. This means a warmer climate will benefit certain crops and regions but harm others. It will also alter the geographic distribution of crop production, causing current crop ranges to move generally poleward.

Carbon dioxide is a related factor that will also affect agriculture. Considerable scientific evidence indicates that today's climate change is being driven in large part by increasing atmospheric greenhouse gas concentrations. Increases in carbon dioxide, the most abundant of greenhouse gases, stimulates the growth of certain classes of crops (so-called C3 crops such as rice, wheat, barley, oats, soybeans, potatoes, and most fruits), while the growth of others (so-called C4 crops like corn, sugarcane, sorghum, millet, and some grasses)

BRUCE A. MCCARL, *a professor of agricultural economics at Texas A&M University, has contributed to the work of the Intergovernmental Panel on Climate Change.* MARIO A. FERNANDEZ, JASON P. H. JONES, *and* MARTA WLODARZ *are graduate students at Texas A&M.*

is not greatly stimulated, but does better under drought conditions. Carbon dioxide effects on production are not strictly positive: Weed competition, for instance, also will be stimulated. However, carbon dioxide effects could partially offset yield losses that will occur solely based on temperature and precipitation changes.

And these are far from the only climate change factors with important effects on agriculture. Sea-level rise caused by ice melt and thermal expansion of the ocean could inundate substantial areas of agricultural land, particularly in low-lying producing countries such as Egypt, Bangladesh, India, and Vietnam. Pest populations are likely to be affected, and significant shifts have already been observed in pest extent and incidence. Observations show that weed and pest damages are greater in warmer areas, portending an expanding region of damage as the climate warms. Decreased frequency of extreme cold spells can also stimulate pest spread, as has been observed in North American forests with the wide spread of the destructive pine bark beetle.

Climatic extreme events—for example, droughts, floods, heat waves, and extreme cold—are projected to increase, and these can lead to lower, less stable agricultural yields, while also inducing greater incidence of famine and shifts in land use away from cropping. The Intergovernmental Panel on Climate Change (IPCC) recently published a report on extreme events suggesting that droughts may intensify in many parts of the world, including North and South America, Central Europe, and Africa. This in turn could reduce production and cause domestic and international food prices to increase, as was seen during 2012. Countries whose inhabitants already spend a large portion of their income on food will be most severely affected, resulting in increased malnourishment and poverty.

The IPCC report on weather extremes indicates the likelihood of more heat waves, which would stress water availability, crop production, and livestock production. They could as well decrease livestock disease resilience. The IPCC also provides evidence of an increase in the proportion of heavy rainfall events, relative to total rainfall. This would increase soil and fertilizer runoff, in turn causing water pollution and algae blooms.

Climate variation does not arise from a single source. Earth's climate has always exhibited strong natural variability on a seasonal, annual, and multiyear basis. Such variation originates from interactions within and among the atmosphere, ocean, land, sea ice, and glaciers, among other factors. One widely discussed cause of between-year climate variability is the El Niño Southern Oscillation (ENSO). Arising from interactions between the ocean and the atmosphere, ENSO causes shifts in the jet steam with effects on climate over large areas. For example, in Texas the occurrence of the La Niña phase of ENSO has been associated with the driest years in recorded history, including the record drought in 2011.

Many other major ocean-atmosphere interactions have been identified as contributing factors as well, including longer-term phenomena like the so-called North Atlantic Oscillation. Interestingly, some analysts have projected interaction between climatic change forces and the ocean phenomena with, for example, extreme ENSO events becoming more common and stronger. The jury is still out on whether this is likely to happen.

Crop and livestock yields

Certainly there is reason for concern given climate change effects and natural variability coupled with agriculture's enormous dependence on climate. And this concern is borne out in current agricultural production trends.

Recent years have witnessed substantial variability in agricultural yields. Consider data from the United States. During the 2011 drought in the Southwest, nearly 40 percent of the cotton crop was abandoned, with yields judged insufficient to merit harvest. Cattle were widely sold off. Irrigators in many areas found that they could not pump enough water to compensate for the extremely dry conditions. The net loss was estimated at $7.4 billion. Then came a 2012 drought in America's Midwest, resulting in a corn crop estimated to be 25 percent smaller than expected, and a near-doubling of corn prices.

Increasing variability in yields is also evident in developing countries. In subsistence areas, dry conditions have led to widespread famine in some instances, while extremely wet and favorable conditions can cause an oversupply in markets not capable of moving the commodities, resulting in a collapse in prices.

Some of climate change's damaging effects on agricultural yields are offset by technological progress. Indeed, increases in yield stimulated by research investment and technology dissemination have been a key feature of agriculture for many years. In some areas of the world, food supply has grown faster than the population—leading to declining real prices and enhancing nations' ability to export more food. This also has allowed farmers to devote increasing amounts of land to bioenergy resources.

However, recent years have seen an overall decline in rates of yield growth. In the United States, corn yield growth until the 1970s exceeded 3 percent per year; now it is below 1.7 percent. Many complex factors have led to this result, including reductions in yield-enhancing investment levels. But certainly climate change has been a factor, and will be one in the future. This portends lower future growth in yields relative to demand growth, and perhaps may restrict agriculture's ability to meet the multiple demands now placed upon it. It also calls for larger levels of investment in productivity-increasing factors like research and technology dissemination.

The agricultural impacts of climate change and climate variation show considerable geographic differences, both within and across regions, due to differing soil characteristics, regional climates, and socioeconomic conditions. For example, according to projections reviewed in IPCC reports, rain-fed agricultural production in sub-Saharan Africa will decline by up to 50 percent by 2020. Maize production in Africa and Latin America is projected to fall by 10 percent to 20 percent by 2050. Yet the maize yield on China's Loess Plateau is projected to increase by around 60 percent during 2070–99. Wheat yields in southern Australia are projected to drop by 13.5 percent to 32 percent by 2050, yet over the same period winter wheat production in southern Sweden will increase by 10 percent to 20 percent.

850 million of the earth's inhabitants lack access to a secure food supply.

In areas of Illinois and Indiana, due to an increase in daily maximum temperatures, some analysts project long-season maize yields will decline by 10 percent to 50 percent between 2030 and 2095. However, maize yields in the Great Plains area are projected to increase 25 percent by 2030 and 36 percent by 2095. A warming of 9 degrees to 11 degrees Fahrenheit by 2050 would cause a projected 10 percent decline in livestock yields, on average, in cow and calf and dairy operations in the Appalachian region, the Southeast (including the Mississippi Delta), and the southern plains.

Simultaneously, water is expected to become a growing issue. IPCC projections indicate that water availability within some dry regions at midlatitudes and in the dry tropics will experience a reduction of 10 percent to 30 percent by 2050. The projections also show that, at higher latitudes and in some wet tropical areas, water supplies will increase by 10 percent to 40 percent over the same period. Also, the portion of river basins under severe water stress is expected to expand, with the ability to withdraw water either stabilizing or declining in 41 percent of global river basins. On the one hand, such impacts are expected to be more prevalent in developing countries than in industrialized ones. On the other hand, warming may well help in regions closer to the poles by limiting cold stress, even as it raises the heat stress in regions closer to the equator.

As already hot regions grow hotter, cows and pigs will not eat as much; the heat suppresses their appetites. This will negatively affect their growth performance. Additionally, evidence suggests that higher average temperatures cause lower birth rates and reduced milk and wool production. A study by the US Department of Agriculture (USDA) estimates that additional stress from heat will cause the beef industry to lose $370 million per year. This, coupled with altered feed availability, could cause large pole-ward shifts in regions of livestock production.

Forage properties are also at issue. Under hotter conditions in already hot areas, the quality of forage deteriorates and its protein content worsens. Also, grass and hay are projected to grow at a slower pace; thus livestock stocking rates per unit of land area will go down.

Livestock diseases and pests are projected to become more prevalent. For example, higher temperatures have been found to increase the probability of avian influenza outbreaks, raising threats to poultry as well as human populations. In Niger, an invasion of desert locusts in 2005–06 caused massive damage to pasture lands and was followed by an extreme food crisis, with around 4 million people facing chronic famine.

Collectively, the water and agricultural implications of climate change will add to the developmental challenges of ensuring food security and reducing poverty.

Adapt and Mitigate

The 2007 IPCC report identifies two basic forms of actions for addressing the impact of climate change on agriculture. First, society can alter agricultural production processes to accommodate the altered climate. Second, society can act to reduce greenhouse gas emissions in an effort to mitigate (or limit) the extent of future climate change, with farming playing a role in this effort. Climate change likely will affect agriculture negatively where societies do not find ways to adapt.

To prepare for changing climate conditions, policy makers require a clear picture of the risks that their country or region will face in the future. The extent of these risks is generally uncertain. Traditionally we have used historical climate behavior as a starting point for predictions. That is, we typically assumed that any climatic cycles or phenomena that occurred in the past will likely recur (for example, the 100-year flood). This was a reasonable approach in earlier times, but in a future with climate change the repeatability of the past is not likely to hold.

Climate change alters the variability of droughts, heat waves, and floods. Not only will it affect future average crop and livestock yields; it will also make more uncertain the year-to-year variations in production. Thus, it will not be appropriate to assume that, for example, an observed flood or drought of a particular severity that occurred once in the past hundred years will occur with such frequency in the future.

A warmer climate will benefit certain crops and regions but harm others.

Agriculture can be adapted to climate change by altering the management and location of production. Indeed, adaptation is not a new concept in agriculture. Producers in any region are faced with local conditions in terms of climate, pests, water availability, demand, land suitability, environmental regulation, and market competition. In turn, they choose an appropriate mix of crops, livestock, and management techniques to accommodate those conditions. As we have noted, for instance, areas where rice and cotton are grown are generally hotter than areas where wheat grows. As climate heats up, relocation of negatively affected crops toward the poles is an effective adaptation.

At the same time, selection of animal, crop, and forage species or breeds that are more resistant to heat and drought might help, along with the provision of irrigation and shade for animals. These possibilities will aid agriculture's adaptation, but likely will not alleviate difficulties in particularly vulnerable regions. In these regions a lack of resources such as available capital, producer education and knowledge, and available information, together with the infeasibility of certain actions, might preclude full adaptation, leaving residual damages from climate change.

In general, adaptations can be private and autonomous or public in nature. Producers often undertake adaptations autonomously. For example, warmer conditions historically have caused crop shifts. In the United States, the geographic center of corn and soybean production in 1990 showed a northwestern shift of approximately 120 miles, in comparison with production locations in the early 1900s. More recent data show a further northwestern shift of more than 75 miles since 1990.

Policy strategies

Public adaptations, on the other hand, encompass actions that are beyond the capabilities of individuals, or are far too costly for individuals to invest in, or once developed are not the kind of practices that an individual can patent and be paid for by other users. Public adaptations range from developing heat-resistant crop and livestock varieties, to disseminating climate-forecasting information to populations that need the knowledge in order to adapt.

For one example, the US National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, and the US Geological Survey have created a famine early-warning system using satellite information on soil moisture levels and crop health. The system is designed to help farmers adapt to projected unfavorable climate change and to lower the cost of extreme events.

Publicly supported adaptations can also involve the development of institutions such as financial systems that reduce farmers' exposure to risk, or the implementation of a freer trade policy that more readily provides food to areas where climate change reduces production. However, in this regard there is a serious risk of public underinvestment. The World Bank estimates a current need for between $9 billion and $40 billion in annual climate change adaptation funding. The United Nations' Food and Agriculture Organization (FAO) indicates that in 2011, some $244 million was dispersed to all countries in total.

Agricultural damages from climate change impacts are expected to be greatest among countries with the least ability to adapt, primarily poor countries. When such nations face a prolonged drought or multiyear crop failures, their strained food supply could cause a collapse of rural production, large-scale out-migration, social unrest, and famine. The severity of impact is related to the limited human and physical resources available for investments in technological knowledge, human capital, water and food storage, processing, and distribution.

What's at Stake

There is increasing evidence that the welfare of current and future generations will depend heavily not only on atmospheric greenhouse gas concentration levels, but also on the actions taken to stop and reverse greenhouse gas accumulation. In 2012 carbon dioxide levels in the atmosphere were measured to be more than 40 percent higher than pre-industrial levels. Agriculture itself is the source of between 50 percent and 70 percent of methane and nitrous oxide emissions, and atmospheric concentrations of these greenhouse gases also have increased significantly.

Agriculture can play a role in reducing atmospheric greenhouse gases by increasing carbon storage (sequestration), increasing tree planting, easing tillage, converting croplands to grasslands, or otherwise managing to increase soil organic content. Agriculture can also help avoid emissions by reducing fossil fuel use, altering nitrogen fertilization practices, better managing ruminant livestock and manure, and reducing rice methane emissions, among other means. Finally, agriculture can provide substitute products that can be used in place of fossil-fuel-intensive products. For example, biomass-based feedstocks can be substituted for liquid energy or electricity production, and new building materials can replace steel and concrete.

In considering adaptation and mitigation, one must be cognizant of the fact that land use for some environmentally adaptive alternatives can come into competition with land use for the food supply. The recent corn ethanol boom in the United States is an important example: An expansion of ethanol consumption from roughly 6 percent to nearly 40 percent of the US corn crop between 2002 and 2012 has, coupled with other factors, led to increased land use, diverted production, higher food prices, and some degree of increased price instability.

Rising food prices are not the only problem caused by expanded mitigation activity. Increased biomass production and utilization (for example, removal of corn residues from fields) cause increases in pesticide use, ground water depletion, soil erosion, and biodiversity loss. Furthermore, the rise in commodity prices can induce expansions in domestic and international agricultural land use, possibly leading to greater rates of deforestation and losses in associated carbon sequestration.

FAO figures show that the world's agricultural production has more than doubled in the past 50 years, and in developing countries it has more than tripled. The amount of available food has grown steadily, allowing the fulfillment of basic nutritional requirements for an increasing share of a growing global population. In part, advances in farmers' management skills, fertilizers and pesticides, and irrigation supply have contributed to increasing crop productivity in formerly famine-prone areas, particularly in Africa.

Still, the USDA estimates that 850 million of the earth's inhabitants currently lack access to a secure food supply. Oxfam, an international organization for famine relief, recently projected a doubling of prices for the world's staple food products over the next 20 years, with half of the increase attributed to climate change. This would likely result in major food security issues, particularly in areas of Africa, India, and Southeast Asia.

Population growth also contributes to the problem. By 2050 the world is projected to have 3.3 billion more mouths to feed. The challenge is feeding them while also adapting to or mitigating climate change. The dual forces of population growth and climate change will exacerbate pressures on land use, water access, and food security.

It is likely that the impacts of climate change on agriculture will affect everyone. However, the degree of impact will vary depending on how or whether one's society chooses to adapt, and how or whether we act on a national and global basis to limit the extent of future impacts by mitigating atmospheric greenhouse gas concentrations. Both adaptation and mitigation require actions and investments that will compete with each other and with conventional production and consumption. Food security in some regions is certainly at stake. ■