Climate and Agriculture: Change Begets Change

As any farmer will tell you, the production of food relies greatly on the weather. Historically, weather fluctuated from year to year, while climate—the average weather conditions over time—remained much the same. Now, increases in the atmospheric levels of carbon dioxide and other greenhouse gases have led to an unmistakable climb in the global temperatures during the past 20 years. As a result, scientists, farmers, and government officials are struggling to understand what effects a permanently warmer climate will have on agriculture.

A Livermore study modeled the effect of climate change on six perennial crops grown in California: wine grapes, almonds, table grapes, oranges, walnuts, and avocados.

Lawrence Fellow David Lobell is working with colleagues from Livermore, the University of California at Merced, Carnegie Institution, and Stanford University to examine the relationship of global warming and food production. Climate change research at the Laboratory supports the Department of Energy's mission priorities in energy and environment. Lobell's team is modeling the climate-induced changes projected for agricultural regions such as the Central Valley of California and how these changes will affect crop growth. "We're determining the risks that climate change presents to food production and the food security of society and what actions we can take to minimize those risks," says Lobell. "These concerns have received surprisingly little attention in the past. The climate expertise and computer resources at Livermore make it a great place to explore this issue."

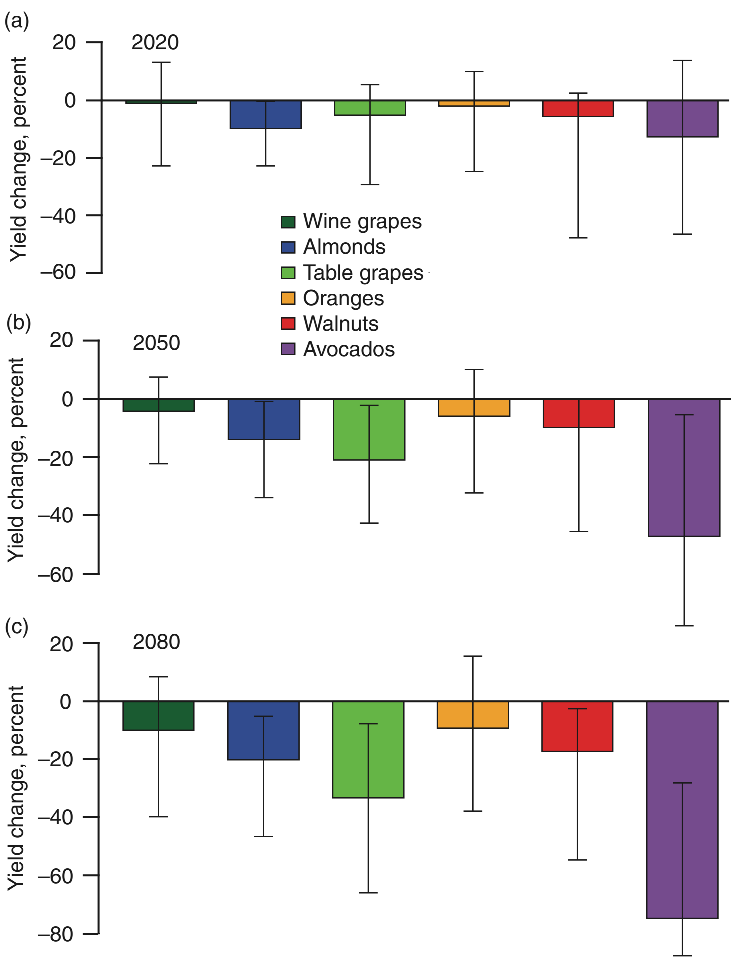
About 11 percent of Earth's land surface is used to grow crops, and 40 percent of the world's food supply comes from the 2 percent of land that is irrigated. In California, agriculture is important to the state's economy, but changes in the industry would have repercussions far beyond the state's borders. As the nation's leading producer of nearly 75 different crops, California supplies more than half of all domestic fruit and vegetables. In fact, California is the sole national producer of both almonds and walnuts. It produces 80 percent of the world's almond crop and a high percentage of fruits, vegetables, and other nuts. Statewide, agricultural income from sales was $27.8 billion in 2003, 13 percent of the U.S. total.

In a recent study, Lobell modeled the effect of climate change through 2080 for six of California's most valuable perennial crops: wine grapes, almonds, table grapes, oranges, walnuts, and avocados. "In California, 20 to 30 years is the productive lifespan for most of these plants," Lobell says. "If we can get a picture of how the climate will change during this interval, we can evaluate what that means in terms of the projected crop yields. In addition, keeping the time frame relatively short limits the uncertainty in the modeling results."

Lessons from the Archives

For this study, Lobell and his colleagues used climate models developed by various research organizations throughout the world and stored at the Program for Climate Model Diagnosis and Intercomparison (PCMDI) in Livermore's Energy and Environment Directorate. PCMDI develops methods and tools for comparing the many general circulation models (GCMs) used to simulate the global climate. In addition, PCMDI stores terascale data sets from GCM simulations, making them available to climate scientists worldwide. (For information about recent global climate change simulations, see *S&TR*, June 2006, pp. 25–27.)

Lobell and his colleagues selected climate projections from 22 coupled ocean–atmosphere GCMs, which simulated future scenarios of greenhouse-gas emissions at medium-high, medium, and low levels. Those results were combined with the team's models of crop yield responses, which are based on records of crop yields and weather throughout California since 1980.



Results from the Livermore simulations of climate and crop yield show the median projected change for six California crops by (a) 2020, (b) 2050, and (c) 2080. Error bars indicate the model uncertainty. Although the level of uncertainty is substantial, the overall trend is for decreased yields.

Models Bear Fruit

The projections show variable results for the six perennials studied. Wine grape yields, for instance, changed very little over the next century, but the other crops exhibited moderate to substantial declines in yield. The amount of uncertainty in the results was considerable, but the overall trend was for a decrease in yields. "More than 95 percent of the simulations for almonds, table grapes, walnuts, and avocados showed a negative response to warming by mid-century," says Lobell. "The current climate is either at or above the optimum temperatures for the crops we studied, and all climate models project at least some warming during this period. Also, these crops are irrigated, so the uncertainties in precipitation projections, although large, have a relatively minor effect on the simulations. Of course, these projections assume that precipitation changes do not affect the availability of irrigation water, which is a fairly safe assumption for these high-value fruits and nuts but likely not for other crops."

Lobell notes that many factors were missing from the study. For example, research indicates that elevated levels of atmospheric carbon dioxide can enhance plant production, at least for a time. Scientists generally believe that, with cereal crops, higher carbon dioxide levels will counteract increases in temperature of up to 2°C, the amount of warming that most simulations project will occur by 2050. Beyond that, the warming effect dominates, and crop yields decrease. Scientists have yet to determine whether perennial crops will respond in the same manner.

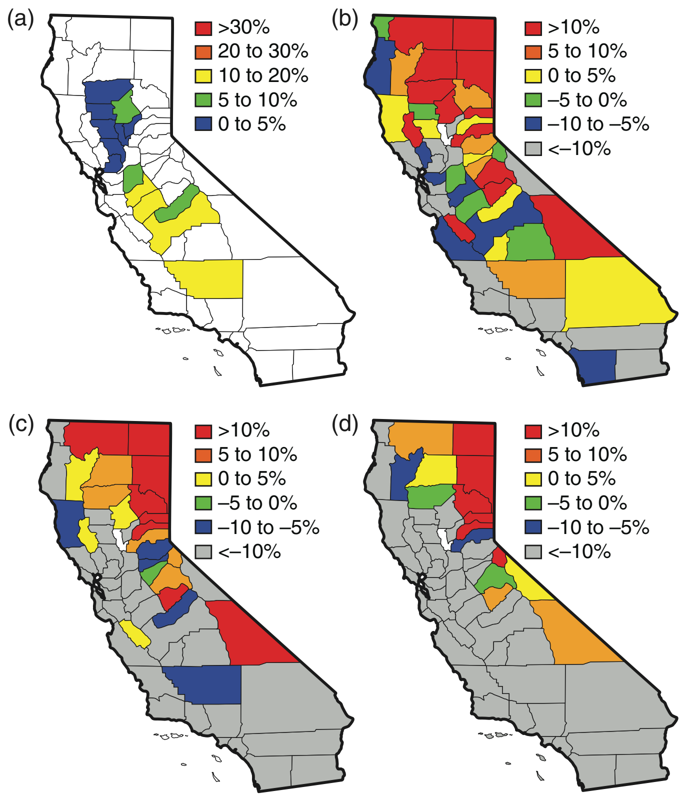
Beyond the Archives

Another issue is that, historically, climate models have not performed well in agricultural regions. Many scientists, including Lobell and Livermore researchers Philip Duffy and Celine Bonfils, are investigating whether the accuracy of regional simulations is affected by farming activities. Global climate models tend to focus on factors that affect the entire planet, such as greenhouse gas levels. At a regional level, however, local activities such as frequency of tilling, crop selection, and amount of irrigation may be important factors in a simulation.

In examining historical data on weather and irrigation changes, Lobell and his colleagues found that irrigation has significantly reduced temperatures in specific agricultural areas in California. This cooling occurs because moisture evaporates into the atmosphere and absorbs energy that otherwise would go into heating the land. Lobell also ran climate simulations to evaluate the interaction of irrigation with greenhouse gases. Without irrigation included, models indicate that most agricultural areas become drier and warmer as greenhouse gas levels increase, with regional temperatures rising 4 to 5°C when carbon dioxide levels are doubled. The reality, however, is that farmers will likely maintain the soil's moisture level by irrigating their crops. When this water is included in simulations, the temperature increase is only 3 to 4°C.

What Now?

Climate change models can also be used to evaluate options for adapting to the new climate. For example, Lobell simulated future yields of perennial crops by county to determine if production could be effectively shifted to more favorable areas. Models of today's climate indicate that much of the current crop area is in counties with the highest simulated yields—that is, farmers have selected good regions for each crop, and the varieties of plants are suitable to the regions. However, with an increased warming of 2°C, the models project that no county in California can produce walnut yields at 95 percent of the current state average. Projections for almonds, table grapes, and avocados grown in a climate 2°C warmer show some areas in the state that would be appropriate to keep yields near or even above current levels. However, these regions are not close to the current growing areas, and shifting production to new areas could be difficult and expensive.



The Livermore climate–crop models can examine options for adapting to a warmer climate. For example, simulations can project almond yields by county, allowing decision makers to consider new locations for future planting. (a) The current area of California almond crops is shown as a percentage of the state's total area. The projected yield for each county (expressed as a percentage of the current statewide average yield) shows options for crop locations given (b) the current climate, (c) 2°C warming, and (d) 4°C warming.

Yields decrease even more when warming reaches 4°C, as do the areas with high-yield potential. These changes are particularly noticeable for oranges, walnuts, and avocados. Still, opportunities may exist to shift production. "The feasibility of relocating crops depends on many factors, such as topography, soils, irrigation infrastructure, transportation infrastructure, and competing land uses," says Lobell. "Making these adaptations a reality will require climate scientists and agricultural decision makers working together."

Lobell is conducting similar studies for regions with crops of more direct relevance to food security, such as wheat, rice, and corn. A recent study concluded that climate change is already having a negative effect on the global production of wheat and corn. The overall goal of this research is to better understand the relationship of climate and agriculture so that informed decisions can be made about crop management and agricultural investments. "In the current world, more than 20,000 people die every day from causes related to hunger and poverty," Lobell says. "With climate change, the number of deaths could double or increase even more. If we can better understand the risks we face and evaluate our options for dealing with these changes, we can decide how much time and money to spend on the problems and what actions we can take to improve our trajectory."

—Ann Parker

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