How will crops fare under climate change? Depends on how you ask

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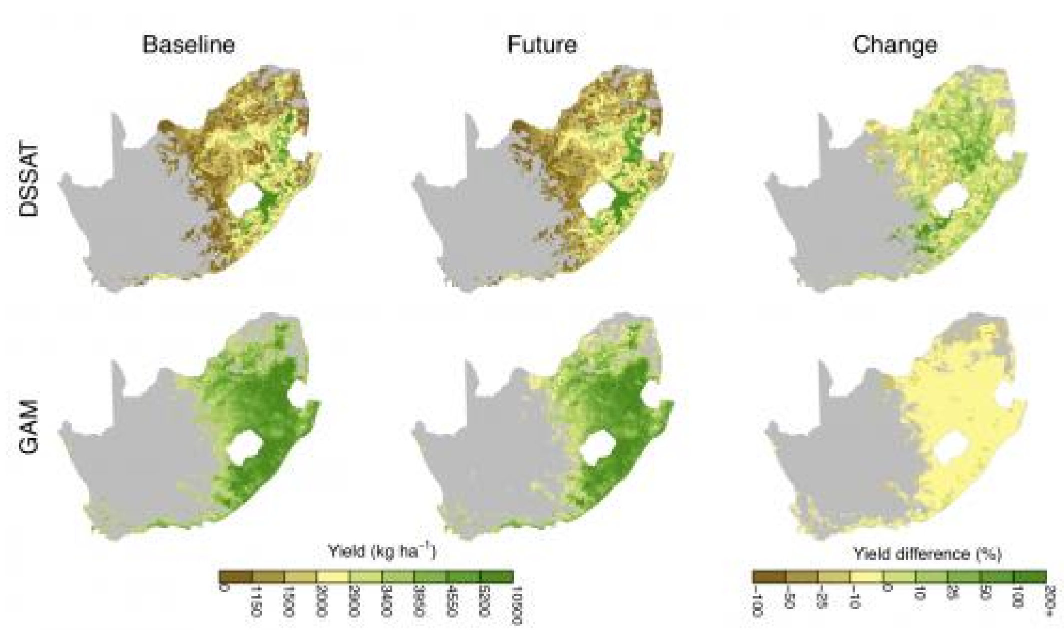


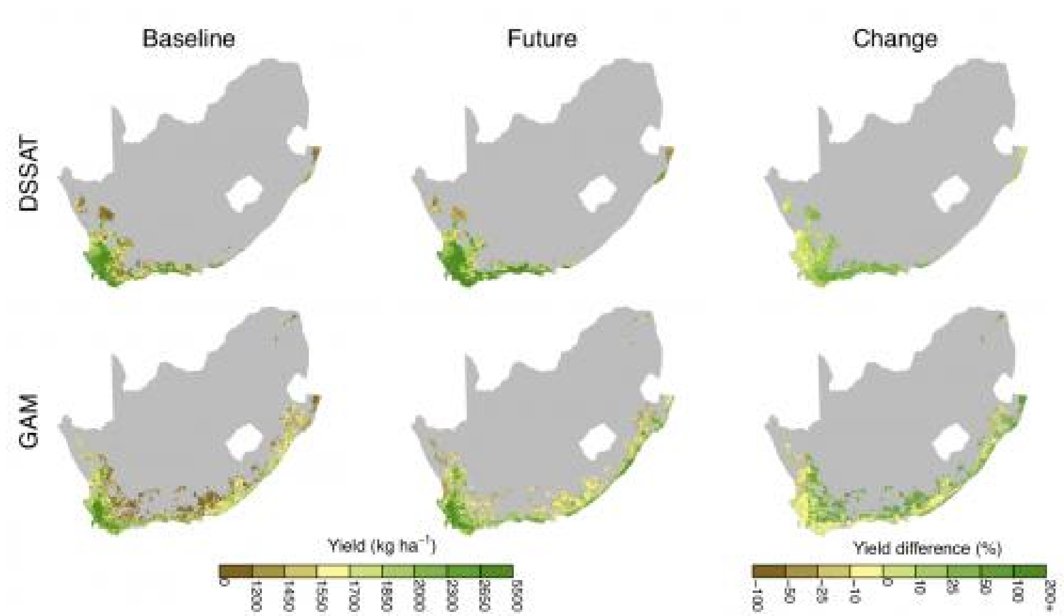
This image shows mechanistic (top row) and empirical (bottom row) simulations compared recent, or "baseline," maize production in South Africa (1979-99) to projected future production under climate change (2046-65). While both models showed a reduction in output, the third column shows that the empirical model estimated a widespread yield loss of around 10 percent (in yellow), while the mechanistic model showed several areas of increased production (in green). Credit: Image by Lyndon Estes

The damage scientists expect climate change to do to crop yields can differ greatly depending on which type of model was used to make those projections, according to research based at Princeton University. The most dire scenarios can loom large in the minds of the public and policymakers, yet neither audience is usually aware of how the model itself influenced the outcome, the researchers said.

The report in the journal *Global Change Biology* is one of the first to compare the agricultural projections generated by empirical models—which rely largely on field observations—to those by mechanistic models, which draw on an understanding of how crop growth and development are affected by the environment. Building on similar studies from ecology, the researchers found yet more evidence that empirical models may show greater losses as a result of climate change, while mechanistic models may be overly optimistic.

The researchers ran an empirical and a mechanistic model to see how maize and wheat crops in South Africa—the world's ninth largest maize producer, and sub-Saharan Africa's second largest source of wheat—would fare under climate change in the years 2046 to 2065. Under the hotter, wetter conditions projected by the climate scenarios they used, the empirical model estimated that maize production could drop by 3.6 percent, while wheat output could increase by 6.2 percent. Meanwhile, the mechanistic model calculated that maize and wheat yields might go up by 6.5 and 15.2 percent, respectively.

In addition, the empirical model estimated that suitable land for growing wheat would drop by 10 percent, while the mechanistic model found that it would expand by 9 percent. The empirical model projected a 48 percent expansion in wheat-growing areas, but the mechanistic reported only 20 percent growth. In regions where the two models overlapped, the empirical model showed declining yields while the mechanistic model showed increases. These wheat models were less accurate, but still indicative of the vastly different estimates empirical and mechanistic can produce, the researchers wrote.



For wheat, the mechanistic model (top row) projected greater wheat yields, while the empirical model (bottom row) suggested that wheat-growing areas would expand by almost 50 percent. Credit: Image by Lyndon Estes

Disparities such as these aren't just a concern for climate-change researchers, said first author Lyndon Estes, an associate research scholar in the Program in Science, Technology and Environmental Policy in Princeton's Woodrow Wilson School of Public and International Affairs. Impact projections are crucial as people and governments work to understand and address climate change, but it also is important that people understand how they are generated and the biases inherent in them, Estes said. The researchers cite previous studies that suggest climate change will reduce South African maize and wheat yields by 28 to 30 percent—according to empirical studies. Mechanistic models project a more modest 10 to 19 percent loss. What's a farmer or government minister to believe?

"A yield projection based only on empirical models is likely to show larger yield losses than one made only with mechanistic models. Neither should be considered more right or wrong, but people should be aware of these differences," Estes said. "People who are interested in climate-change science should be aware of all the sources of uncertainty inherent in projections, and should be aware that scenarios based on a single model—or single class of models—are not accounting for one of the major sources of uncertainty."

The researchers' work relates to a broader effort in recent years to examine the biases introduced into climate estimates by the models and data scientists use, Estes said. For instance, a paper posted Aug. 7 by *Global Change Biology*—and includes second author and 2011 Princeton graduate Ryan Huynh—challenges predictions that higher global temperatures will result in the widespread extinction of cold-blooded forest creatures, particularly lizards. These researchers say that a finer temperature scale than existing projections use suggests that many cold-blooded species would indeed thrive on a hotter Earth.

Scientists are aware of the differences between empirical and mechanistic models, said Estes, who was prompted by a similar comparison that showed an empirical-mechanistic divergence in tree-growth models. Yet, only one empirical-to-mechanistic comparison (of which Estes also was first author) has been published in relation to agriculture—and it didn't even examine the impact of climate change.

The solution would be to use both model classes so that researchers could identify each class's biases and correct for it, Estes said. Each model has different strengths and weaknesses that can be complementary when combined.

Simply put, empirical models are built by finding the relationship between observed crop yields and historical environmental conditions, while mechanistic models are built on the physiological understanding of how the plant grows and reproduces in response to a range of conditions. Empirical models, which are simpler and require fewer inputs, are a staple in studying the possible effects of climate change on ecological systems, where the data and knowledge about most species is largely unavailable. Mechanistic models are more common in studying agriculture because there is a much greater wealth of data and knowledge that has accumulated over several thousand years of agricultural development, Estes said.

"These two model classes characterize different portions of the environmental space, or niche, that crops and other species occupy," Estes said. "Using them together gives us a better sense of the range of uncertainty in the projections and where the errors and limitations are in the data and models. Because the two model classes have such different structures and assumptions, they also can improve our confidence in scenarios where their findings agree."

More information: The paper, "Projected climate impacts to South African maize and wheat production in 2055: A comparison of empirical and mechanistic modeling approaches," was published online ahead of print July 17 by the journal *Global Change Biology*.

Provided by Princeton University