Science Societies

Climate change uproots global agriculture

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Small farms, like the one Francisco Obadiaz (above) works on in Mozambique, account for about 90% of the world's 570 million farms. They are particularly vulnerable to unpredictable changes in seasonal climate. Photo by Jeffrey Barbee/Thomson Reuters Foundation. Source: Flickr/CIF Action.

- In much of the world, climate change is altering regional growing conditions and making them more unpredictable.
- As a result, the world's food-growing areas are on the move, leaving farmers behind.
- How can we secure our future food supply and support the people who grow it?

In much of the world, climate change is altering regional growing conditions and making them more unpredictable. Famers are finding it harder to consistently grow enough food to meet increasing demand. Securing the world's food supply for the future, experts assert, requires us to tally the good and the bad in the current agricultural structure, including the infrastructure and technology in food distribution systems.

Small farms, which account for about 90% of the world's 570 million farms, are particularly vulnerable to unpredictable changes in seasonal climate. Land tended by families for generations may suddenly become nonarable. A change in the timing or intensity of yearly rainy seasons or the El Niño–Southern Oscillation (ENSO), for example, could bring rains or drought at just the moment to wipe out a family's crops.

In early May 2020, the Nzoia River burst its banks. The floods that resulted in western Kenya capped off particularly heavy long rains that killed 237 people and adversely affected more than 800,000. Floods and landslides destroyed homes, schools, roads,

bridges, and more than 8,000 acres (32 km^2) of Kenyan farmland.

Kenya's March–May rainy season (the long rains, as opposed to the short rains of October–December) provides vital moisture to the country's croplands—indeed, maize production was at least 10% above average in 2020—but most Kenyans continue to face some level of food insecurity. In the past few years especially, climate change has caused a geographical shift in which areas receive rain and which suffer drought.

“Normally, we know where the flood areas are,” but the rains the past few years have been “unprecedented,” says Ruth K. Oniang'o, founder of the Rural Outreach Africa Program and 2017 Africa Food Prize Laureate. “We have rain falling in areas that never used to have rain. I used to write all the time about famines and drought…but right now is something different. We can say, ‘Okay, climate variability, it changes every year.’ No. This is different right now.”

A general view shows flooded homes as River Nzoia burst its banks due to heavy rainfall and the backflow from Lake Victoria, in Budalangi within Busia County, Kenya on 3 May 2020. Photo by Thomas Mukoya. Source: Reuters/Alamy.

The differences extend beyond Africa. Farmers in Iran, for example, share similar problems anticipating cycles of drought and floods despite being separated by more than 7,000 km from their Kenyan counterparts. “The recent harsh droughts and heavy floods in the [Middle East] region ruin a major part of food resources,” explains Mohanna Zarei, a water resources engineer at the University of Kurdistan in Sanandaj, Iran. Sporadic precipitation cycles not only reduce crop yields, but can also lead to secondary impacts that worsen food security, like the wildfires that have ravaged the western

United States, Australia, Brazil, and elsewhere.

What compounds climate-related food security issues is wealth and social inequality. Many of the world's smallholder farmers are poor and food insecure; even one lost season can push them from struggling to failing. “Climate change plays a key role as a catalyzer” in amplifying preexisting resource problems and “will influence the quality and quantity of food we produce and our ability to distribute it equitably,” Zarei says.

“It's not quite as simple as moving into less climate-affected areas. It remains an issue of climate and socioeconomic and technological development,” says Weston Anderson, a hydroclimatologist at the International Research Institute (IRI) for Climate and Society at Columbia University in Palisades, NY. Understanding how agricultural practices and policies need to change along with the warming climate and then sowing the seeds of that change could be the difference between farmers thriving where they are or migrating to greener pastures.

Stressing the Climate System

A region's agricultural stability depends on reliable, natural climate variations to bring seasonal shifts in weather. Large-scale climate modes like ENSO and the Indian Ocean Dipole govern a region's temperature, precipitation, and storm activity for months at a time. Climate modes also causally connect distant regions, something that has been increasingly important as agricultural trade has become more global: A climate shift in one food-growing region can also affect crops half a world away.

Maize farmers around the world felt the impacts of climate teleconnections during one of the strongest El Niños of the past 150 years. The 1983 El Niño coincided with the largest global synchronous failure of maize crops in modern record, and recent research has shown that ENSO played a major role in causing that failure.

“The El Niño–Southern Oscillation, because it organizes global weather and global precipitation, it provides structure on the risk of global agriculture by rearranging where we get more drought and less drought in the year,” Anderson explains. “It's not necessarily creating more drought over the entire year, but it might be arranging those droughts in a way that disproportionately affects some of our crop-growing regions.”

Anderson's team found that ENSO is the only mode of climate variability that can impact maize, wheat, and soybean crop production on a global scale. Other large-scale climate modes have more localized influence on certain crop yields. The tropical Atlantic variability, for instance, influences both maize production in western Africa and wheat and soy production in southeastern South America simultaneously, but the North Atlantic Oscillation affects only wheat production in northern Africa and Europe.

“Climate will largely continue to affect our food system through climate variability,” Anderson said. “Often, you see climate change acting on top of this climate variability and exacerbating stresses that are already existing in our food system.” For example, he says, a regional crop might withstand a normal ENSO-related drought but could fail if climate change–induced drought worsens, too.

Going back and forth between the extremes of wet periods from high-intensity rainfall and droughts, can

lead to soils eroding at a fast rate, according to Asmeret Asefaw Berhe, a soil biogeochemist at the University of California–Merced. Altered rainfall patterns can also unbalance a soil's oxygen availability, acidity, salinity, and water-holding capacity and can hinder the formation of new soil.

Down in the Soil

Moreover, climate change also affects what goes on beneath earth's surface. To sustain an agricultural system with consistent, high, and high quality yield, "you need the soil system to first and foremost be able to support plants," says Asmeret Asefaw Berhe, a soil biogeochemist at University of California–Merced. "Plants need physical support from the soil, and they also need nutrients and water to be available in the right forms and in the right time where plants need them."

According to a 2015 report from the Food and Agriculture Organization of the United Nations, about one-third of the world's soil is moderately to highly degraded, and the conditions causing that degradation are, overall, getting worse. Unsustainable agricultural practices cause some of the decline in soil health, and some is caused by climate change, Berhe says. "Hot temperatures, for example, are associated with rapid loss of organic matter from soil. This is a major issue as organic matter is the major storehouse of food and energy for microbes in soil that are key for regulating nutrient availability."

Moreover, "the episodic high-intensity rainfall, wet periods, and droughts, the going back and forth between extremes could also lead to conditions where soils are actually eroding at a fast rate, especially under intense precipitation events," Berhe adds. "That's a major concern." Altered rainfall patterns can also unbalance a soil's oxygen availability, acidity, salinity, and water-holding capacity and can hinder the formation of new soil.

“Climate change reshapes the relationships among crops, pests, pathogens, and weeds,” Zarei says, “and it intensifies several trends, including declines in pollinating insects, increasing water scarcity, increasing ground-level ozone concentrations, and fishery declines. Climate change [has] posed pressures on availability of water resources for agriculture by shifting precipitation patterns, earlier seasonal snow melt, and intrusion of saltwater into coastal aquifers.”

It is true that some areas of the world are becoming more arable in the face of climate change, especially the Arctic. The warming planet pushes the agricultural frontier poleward and into carbon-rich areas of thawed permafrost and peatland. “The climate envelope moving means that certain areas are now able to support different types of habitats,” Berhe says. “But I think it's a little hard to call that improving soil health because of the way we got there.”

“A northward shift in where we grow foods commercially is one of the most likely new agricultural frontiers,” says Merritt Turetsky, and “the cost of imported foods in the Arctic can be exorbitant.” Turetsky is an ecologist at the University of Colorado–Boulder and a science adviser for *Eos*. “Could an increase in commercial or local food production at high latitudes solve this problem of high food prices? Maybe, but it is likely to introduce some complex challenges for northern regions and the people who depend on those lands.”

Declining soil health around the world also encourages governments to cultivate untouched ecosystems, which can worsen environmental problems in the long run. For example, “we know that drainage of tropical peatlands for palm oil production has released large amounts of stored peat carbon to the atmosphere,” she continues. “As a society, we must protect our northern peatlands and carbon-rich soils from drainage and cultivation.”

During a drought caused by El Niño, two women in Mozambique do their best to dig another piece of land from which they foresee a chance of good harvesting even though the soil tends to get dryer. Photo by Leopoldino Jeronimo/Kepa.

Short-Term Fixes Make Long-Term Problems

When it comes to humanity's role in the decline in soil health and the growing unpredictability in crop yield, some aspects are out of farmers' hands: rapid urbanization, inefficient infrastructures, unstable political relations, and war. Problems like widespread poverty, hunger, government corruption, gender inequality, and lack of education multiply food security issues around the globe.

However, some of the ways in which farmers mitigate agricultural uncertainty, which may raise short-term yields, actually worsen growing conditions in the long run. The land's “ability to provide the food, feed, and fiber that we were getting from them is getting compromised,” Berhe says. “And so the only way to keep the lands productive, then, is to keep pumping them full of supplements in the form of fertilizers, in the form of irrigation water, in the form of tilling them even more destructively” than we do now.

When crop yields go down, farmers try to expand into new land. “But sometimes extending into other areas means that people are now working on marginal lands that we know are susceptible for degradation,” Berhe explains. Marginal lands often already have poor soil or are prone to erosion. “That could play out in very disastrous ways

when people move away from their home or expand their production systems."

Also, lands might be marginal because they are wet, Turetsky adds, and wetlands or seasonally flooded lands tend to store more carbon than more productive lands do. "This means that extending agricultural practices can release more greenhouse gas to the atmosphere as those new soils are disturbed."

The use of fertilizer can also cause significant long-term environmental damage. "The issue of fertilizer is a central concern in the Senegal River Valley," says Mor Ndiaye, an agriculture engineer and soil scientist who works with smallholder rice farmers in the valley. Ndiaye works at SAED (Société Nationale d'Aménagement et d'Exploitation des Terres du Delta du Fleuve Sénégal et des Vallées du Fleuve Sénégal et de la Falémé) in Saint-Louis, Senegal.

"As the use of fertilizer in agriculture has become more and more essential, however, the quality of the soil is not very often taken into account when it comes to the purchase of fertilizer by farmers [and] producers," Ndiaye adds. "Many growers believe that increasing the amount of fertilizer is synonymous with good yield."

However, "adding nitrogen fertilizers into agricultural areas is one of the most important causes of nitrous oxide emissions to the atmosphere and the one that we have the hardest time taming," Berhe adds. Nitrous oxide is the third most prevalent greenhouse gas. "It's a pretty viscous cycle."

Irrigated cultivation of rice paddies, seen here, accounts for roughly 70% of Senegal's total annual rice production. Developing a sustainable irrigation infrastructure has governed much of the agricultural growth in recent decades and will continue to play a key role in our future food security. Source: Africa Rice Center, CC BY-SA 3.0

A lack of data, too, crops up when trying to secure agricultural production. Remote-sensing data via satellite can provide environmental information like temperature, moisture, and plant cover, but it has data gaps. “Often, remote sensing can get us 90% of the way there,” says Matthew Cooper, an environmental geographer at the Harvard Data Science Initiative in Cambridge, MA. “You do need a lot of ground data to validate the remote-sensing variables. Measuring the actual rainfall on the ground or measuring actual crop yields on the ground will always be more accurate than what you're trying to estimate from space.”

Moreover, smallholder farmers are more likely to thrive if they can analyze soil samples before buying and cultivating new land, but those data “are sometimes difficult to obtain given the often exorbitant cost,” Ndiaye says.

Satellites can't collect data on “things related to food systems around trade and access. And market prices are impossible to remote-sense and have to be dealt with on the ground,” Cooper says. However, many governments lack resources for on-the-ground data collection initiatives as they tackle more immediate concerns or they attempt to mask the extent of environmental problems, for example, as happened with deforestation in Brazil

Cultivating a Food-Secure Future

The agricultural market has become irreversibly global, and with most nations far behind on climate goals, the impact of climate change on farmers is unlikely to abate. What can scientists do to support more sustainable agriculture in current food-growing regions and maintain soil health in new growing areas?

In some of the most food-insecure regions of the world, it's difficult to pinpoint what actions are needed because food security research simply doesn't cover those areas. According to a recent study that text-mined more than 16,000 abstracts from the food security literature, some of the most food-insecure regions of the world have very little presence in food security research, whereas some regions with high food security are overrepresented. “Researchers tend to cluster in the countries where you're not at risk of a sudden civil war or there's already established research institutions or where people have already built full careers,” says Cooper, who was the lead researcher on the study. In more unstable areas, “local policymakers there are pretty well informed of the local situation, but…it seems like places outside the Anglosphere are less visible to the global community.”

Improving data access is key. Even without on-the-ground data networks, “we can tell a ton of stuff, especially about anything environmental, from remote sensing,” Cooper says. “You can get indices of vegetation health, precipitation, rainfall, droughts,” but that information needs to make its way to farmers in a way they can use.

Work like Ndiaye's helps connect smallholder farmers in developing agricultural areas with high-level data products like digital soil maps. Access to that information has helped rice farmers in the Senegal River valley strengthen the capacity of their agricultural sector and establish trade partnerships among farmers, suppliers, and buyers.

Most experts agree that water availability will continue to be a bottleneck in expanding current agricultural areas and establishing new ones. “Irrigation uses 66% of annual water withdrawals and is the single largest human use of water,” Zarei says. But in some areas of the world, including some Middle Eastern countries, she explains, water resources are being used as political leverage rather than a common resource to support regional stability.

Moreover, the past 70 years or so have seen “something like a 200% increase in irrigated agriculture area,” Anderson says, “and around 50% of that is not sustainable in the sense that we're drawing irrigation water unsustainably from either surface water or groundwater.”

Cities like Aqaba, Jordan; Bangkok, Thailand; Kampala, Uganda; Lima, Peru; and Manila, Philippines have shifted to more sustainable water usage “by reusing their wastewater and using this recycled water in the energy sector, food industry, agricultural irrigation, water sector [and] transitioning to a circular economy,” Zarei says.

A caravan of thousands of migrants from Central America, en route to the United States, on 27 Oct. 2018. “What we have found…for the human migration that we saw in recent years from Guatemala, is that it's related to a multiyear drought

that occurred between 2015 and 2017," explains Ángel G. Muñoz, a climate scientist at IRI. Photo by Ueslei Marcelino. Source Reuters/Alamy.

Looking back at agricultural production since 1950, Anderson adds, much of agriculture's geographic shift is tied directly to improvements in irrigation such as where rice is grown in China. "When we're thinking about the future and future responses to climate change and the possibility of moving things out of these hotter regions," Anderson explains, "it really remains intertwined with our ability to sustainably use water and to build irrigation infrastructure in a way that is conducive to growing these crops where we have the available land and nutrients."

Vulnerable Beyond Climate

This past year's East African floods may have boosted crop yields and eased food security concerns for people in rural areas, but the relief is temporary. "Climate impacts are 'triggers,' not the main drivers" pushing smallholder farmers into poverty and insecurity, Ángel G. Muñoz says. Securing the world's future food supply is as much about equity and economic stability as it is about sustainable agriculture, he says.

Consider, for example, push factors driving the recent caravan of thousands of people from Central America, and Guatemala in particular, toward the United States. "What we have found…for the human migration that we saw in recent years from Guatemala, is that it's related to a multiyear drought that occurred between 2015 and 2017," explains Muñoz, a climate scientist at IRI. Smallholder farmers on the brink of poverty faced year after year of poor harvest, lost income, and political instability that finally forced them to migrate northward in search of a way to support their families.

"What we have found is that actually although there is a clear climate signal," he says, referring to the drought, "we do not see a very important climate *change* signal in this

particular migration….Socioeconomic factors and understanding the local vulnerability of the population is far more important than actually thinking in terms of only one stressor," such as climate change, driving farmers to new areas.

Not all countries or regions face the same socioeconomic problems as Guatemala, but that example highlights the need for climate-smart agricultural policies to consider vulnerabilities beyond climate and account for socioeconomic context. "That makes it a difficult problem to approach," Anderson says, "because it's certainly not something that can be solved entirely by scientists, or entirely through climate forecast–related approaches, or entirely in a policy sphere. You need all of these components, and so a lot of the work really is getting the right people talking to each other."

The particulars of those components, Oniang'o says, greatly depend on the country, but each vulnerability makes any agricultural adaptation solution that much more difficult to accomplish. In many U.N.-designated developing economies, girls and women are severely undereducated and underrepresented in the workforce. In some countries, government corruption prevents monetary aid from reaching farmers in need. Most countries, however, are missing the mark at organizing a migration of agricultural areas and supporting the farmers needed to make it work, she says.

"Even when new policies come up, or new trade practices come up, or when the world order changes—even if it's supposed to be in a positive way, it doesn't affect smallholder farmers positively," she says. "I see increasing vulnerability because we have not been able to address the poverty issue, low income, and hunger for many of the people I have been working with."

"The people themselves say, 'We have to move. We have to move from here.' But someone must organize them to move," Oniang'o adds. "It needs to be national policy,

but implemented locally, and keeping vulnerable people in mind so that we don't push them to the edge."

In the end, the paths leading toward a climate-smart global agriculture may already be well worn by generations of farmers. "Indigenous communities in the north who rely on country foods that they harvest or hunt tend to be the most food-secure communities," Turetsky says. "This is because these communities and traditions value the health of the boreal forest or the Arctic tundra. Any changes in local or commercial food production that do not uphold this value of the land or water may interfere with cultural traditions and practices. We must take the lessons learned from historical and existing food-producing regions and ensure we don't repeat the same mistakes."

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Back to issue

Back to home
