Critical Opportunities for Collaborative Research Among Nations

Adaptation of Agriculture to Climate Change: Is There Time?

We are suffering from a surfeit of global crises, each pushing aside the previous one in rapid succession. The current global financial crisis has adumbrated last year's global food and energy crises and even the ever-looming climate change crisis.

But deal with them all we must. My message today is a simple one. The coming changes in earth's climate have profound implications for our ability to feed ourselves. The nexus between the climate change and food crises offers and opportunity – I would say even that it urgently demands that scientists from many nations and diverse disciplines address join to address.

Tom Friedman has attracted a great deal of attention over the past few years with his declaration that the world is flat. By this he means that the Internet revolution and globalization has put all peoples of the world on an equal economic footing. A comforting message. But despite the extraordinary increase in our ability to communicate and access information, even Friedman is beginning to see that things aren't quite so simple. He now concedes that the world is also rather warm and a bit crowded. In his new book, Friedman addresses climate change, energy, economic development, and preservation of biodiversity.

Curiously missing in his call for a Green Revolution is what we generally mean by a Green Revolution and that is what must be done to increase the food supply for a crowded world. Indeed, a crowded world with a changing climate.

What will it take to grow food for the 9 or so billion people expected to populate the Earth by mid-century – and meet the growing demand for meat as people become increasingly affluent? And how might we expect climate change to affect the crops we grow and where we can grow them?

The Earth has warmed over the past 100 years by about 0.85^{o} C. It is, by now, not terribly contentious to say that this is anthropogenic. The CO_2 concentration has increased by a third since 1750, predominantly due to the burning of fossil fuel, but also because of deforestation. What is critical to absorb from this picture is not just the recent jump, but the stability of the atmospheric CO_2 content over the past several hundreds of thousands of years. The troughs, which correspond to ice ages, are at about 180 ppm and the peaks, when the Earth was warmest, is in the range of 280 ppm.

We're at roughly 386 ppm today. According to atmospheric scienctists, even under the best case scenario, atmospheric CO_2 is likely to double again to somewhere in the neighborhood of 700 ppm. This rate of increase is the highest in the last million years. More importantly, the rate of increase is between 100 and 1000 times faster that the rates observed historically.

Here's where we're going with global temperature, shown with respect to the temperature in 1900. Black lines are observed temperatures, smoothed and unsmoothed. red, blue and green lines are Hadley Centre simulations with natural and anthropogenic forcing. Yellow is natural only. The asterisk is the 2003 Eropean heat wave of 2003.

No matter what projections you use, no matter how rapidly we bring our greenhouse gas emissions under control, such summers will become more frequent in the coming decades and will be the typical summer in just a few decades. Our crops were sculpted by people over tens of thousands of years in this moderate temperature range. Let me show you what humans have done to transform plants genetically into human food plants.

Well before science formally entered the agricultural arena, humans made some spectacular progress in the genetic modification of plants to make them better food crops. Let me show you how people transformed a grass called teosinte to our modern maize plant (also known as corn). It originated from from this grassy relative, called teosinte. Corn and teosinte are so different that they were originally assigned to different species. Over a few thousand years, people have converted this grass into one of humankind's three food crops, a plant that produced packets of protein, oil and cornstarch tightly held on a huge – and highly unnatural – structure we call an ear. And yet these two plants are so closely related that they can be crossed and the off-spring are everything from what looks like teosinte seeds to small and medium-sized ears of what is recognizably corn. Teosinte seeds are produced at the top of the plant, like those of other grasses and are inedible. In fact, they have silica deposits in their surface layers – they're hard as rock.

The truly dramatic expansion of the ear took place largely during the 20th century, when it was discovered that seeds from a cross between two highly inbred, rather small and weak plants gave much more vigorous plants with much bigger ears in the first generation. This is called hybrid vigor and is the basis of our current extraordinarily productive hybrid corn varieties. We've done the same with wheat…… and rice.

What does climate change hold in store for these, the crops that today feed the world?

Let's look a closer look at the summer of 2003 – an outlier historically, but a harbinger of things to come. Plotted here is the number of summers in which the temperature deviated from the typical average for France over the past hundred years or so. The average temperature the summer of 2003 was 3.6^{o} higher than the average summer in 2003, although rainfall was normal. We all heard about how bad this was for people: somewhere between 30 and 50,000 people died from heat-related causes that summer. What we didn't hear much about was the effect on crops. Italy saw a 36% decrease in maize yield, while France experienced a 30% reduction in maize and fodder yields, a 25% decrease in fruit harvests and a 21% reduction in wheat yields.

Summer temperatures this high will become more frequent in the coming decades and by midcentury, this could be the average summer.

Plant processes that determine growth and yield are highly temperature dependent. Any given crop has an optimum temperature range for maximum yield. The optimum growth temperature is generally the optimum temperature for photosynthesis, the process by which plants convert atmospheric carbon dioxide to sugars powered by the sun. This optimum is not completely fixed, but it isn't infinitely flexible either. Our familiar crops are toast up around here.

Our familiar crops don't do well at these temperatures, particularly if it's dry, as well. Even a brief period of very high temperatures at the critical time of flowering and pollination can devastate a crop.

Temperature also influences how fast a plant develops and reaches maturity. Higher temperatures speed plants through their developmental phases. Annual crops like corn, wheat and rice set seed just once and then stop producing. This figure shows that as temperature increases from the crop's optimum, the growing period is shorter. Both the shortening of the growing period and the decrease in photosynthesis at higher temperatures reduce yields.

What about the possibility that higher carbon dioxide concentrations will speed up photosynthesis? Well, there are two types of plants, designated C3 and C4, which differ in how efficiently they photosynthesize. The C3 are the less efficient ones and benefit much more from increases in carbon dioxide than C4 plants. Many crops, including wheat, rice, potato, bean, most vegetable and fruit crops, -- as well as many weed species – are C3 plants. But the C4 group includes important food crops, as well, including maize, millet, sugarcane, and sorghum, as well as many pasture grasses and these will benefit little from a CO_2 doubling.

However, it's hard to pin too much hope on such boosts in photosynthesis. While yield boosts of 20-35% have been reported when measured in C3 crops, these are under the best growth conditions. Out in the field, under less than optimal water availability and fertilization, the effect of high CO_2 can even be negative..

Unfortunately, heat – which often goes hand in hand with drought – can trump CO_2 anytime.

Of course, there's irrigation. But many countries are over-pumping aquifers unsustainably. This includes all three of the biggest grain producers - China, India, and the United States. More than half the world's people live in countries where water tables are falling.

Here are some more sobering statistics. The introduction of science into agriculture started about here, roughly at the end of the 18th century. It was also about this time that Malthus wrote his famous essay predicting that humanity was doomed to famine because it reproduced faster than it could expand the food supply. Science-based agriculture, including the invention of a process for converting atmospheric nitrogen into fertilizer, supported a tripling of the world's population. There was a resurgence of Malthusian predictions at midcentury, but happily, these were not realized because of the Green Revolution, which, combined with other advances in scientific agriculture, managed once again to keep agricultural productivity ahead of population growth. The population experts are expecting another roughly 3 billion people to be added to the planet's population by midcentury. That's somewhere in the neighborhood of 9 billion people. Combined with increasing affluence, the demand for food is expected to double by midcentury. Will the warming climate open lands for cropping farther north? Probably, though how much is uncertain. What is quite certain by now is that climate change will squeeze those farther south as soil moisture declines. This will affect the most populous countries, countries whose populations are even now growing the fastest.

And here's another sobering factoid: the amount of arable land has not changed for more than half a century. This is because we're losing it to urbanization, salinization, and desertification as fast as we're adding it. As well, the world is becoming increasingly aware of the devastating contribution to global warming caused by the destruction of tropical forests.

What are the options? 1) More efficient agriculture, particularly with respect to water use, is a must, along with more reinventing the water economy – there isn't a moment to lose. 2) Intensive crop breeding and 3) modern molecular genetic modification for both drought and heat tolerance, as well as insect and desease resistance. 4) And the development of new crops. These are not optios, they are imperatives.

Water efficient farming is being pioneered in Israel's Arava Desert using a range of methods ranging from popcorn soils that hold water tenaciously to watering with brackish water generally considered unfit for other agriculture.

On the island of Spitzbergen in the far frozen north of Norway there is a remarkable structure called the Svalbard Global Seed Vault. In chambers deep in a mountain whose temperature never rises above freezing is a storage chamber, further cooled to a temperature of -15 degrees Celsius. In it are seeds of some 70,000 varieties of the 64 of the world's major food crops. The Global Crop Diversity Trust, which also works to catalog and distribute these seeds, is motivated by the belief that it is this diversity that will be the source of the genes we will need to develop plants that can grow on a hotter, drier planet. And certainly this is an important source of genes and genetic variation.

But the fact is that over the entire (more than) 10,000 year history of agriculture, the CO_2 levels in the atmosphere were between 180 and 280 ppm. Were at 389 now. It's not unlikely that we'll hit 700 ppm before we get this problem under control. That's going to mean that it'll get hotter and drier than our major crop plants have experienced before. Moreover, the change is happening much more readily than plant breeders have experienced historically.

I rather think we should also be scrambling to explore and understand organisms – not just plants – that have evolved to survive and thrive in the parts of the earth that are already the hottest and driest. We'll need to understand how they survive. We'll need to capture the genes that make it possible. If we're lucky, we'll be able to use these to arm some of our super-productive crops plants to survive and thrive under such conditions.

The good news is that over the past half a century, we've developed techniques that can be used to move gene just one or a few genes at a time between plants and other organisms that can't be crossed genetically. Here's the kind of damage corn borers do to corn -- this is one of the most damaging of corn pests. This is an ear of corn on a transgenic plant carrying a bacterial gene that codes for a protein that is toxic to the larvae of the plant pest, but not to animals or people. It's called Bt because the gene comes from another soil bacterium, Bacillus thurengiensis, which has long been used as a biological pesticide. The same techniques can be used to introduce genes that will increase the ability of crop plants to tolerate hotter and drier conditions.

Unfortunately, there are still well-meaning people around the world who believe that GM crops are dangerous, their beliefs fueled by misinformation – even disinformation – on the Internet, from public interest groups and the communications media. Although some European countries, particularly Spain, are growing GM crops, much of Europe, Japan – and most of Africa – remain adamantly opposed to crops improved using molecular techniques. These persistent perceptions have resulted in restrictive and costly regulation of such crops – even banning of both their use and even to their import as food aid. There is much work to be done to communicate the safety record of GMOs to a skeptical public.

And finally, there is much experimentation to be done to identify new plants and new forms of agriculture suited to a hotter world. Here are some examples.
Kibbutz Ketura, funded by USAID and run in the Arava Desert of Israel by Elaine Solowey, collects and explores the utility to humans of a variety of plant species indigenous to Asia, Africa, Australia, and the Americas. What they all have in common in the capability to be compatible with desert conditions. Another approach is that of the Seawater Foundation, headquaratered in Mexico. It is promoting salt water agriculture based on salt-tolerant species in countries around the world.

I am very confident that we have the tools, the talent and the genetic variation needed to prepare this populous planet to feed itself in a warmer future in which our current crops may not do so well. Developing an agriculture for a warmer planet is, indeed, an imperative for international collaboration. We are all denizens of the same planet. And there's not time to waste.