Feature

Food security in the times of climate change

Models predict that climate change will affect the world's poorest people most severely. Which strategies might help to avert disaster in the developing world? **Michael Gross** finds out.

At the end of 2012, the Kyoto protocol was due to expire, leaving the world unprotected in the face of the continuing increase of carbon dioxide emissions and a temperature change that will not be constrained by the famous 2°C target, now rapidly becoming obsolete. In a dramatic push beyond the scheduled end of the meeting, the recent climate conference at Doha managed to scramble up an extension of the Kyoto agreement for another eight years.

The idea is to buy time to make a new, improved international agreement that covers the developing world as well. Experience with the recent rounds of climate talks shows, however, that a binding, global agreement will be phenomenally hard to achieve. Considering the current priorities set in politics, where the financial crisis has all but pushed environmental concerns off the agenda, a climate agreement may fail to materialise in time to limit temperature rises to levels that could reasonably be described as safe.

Climate change is in part caused by agriculture, both directly through unsustainable farming activities and indirectly via land-use change. In turn, it affects yields and crucial parameters, such as water availability. It may force farmers to change their methods, which may produce a vicious circle and more unsustainable practices.

A recent report commissioned by the UN has predicted that by 2050 the global yields of wheat and rice could fall by 13 and 15 percent, respectively. By the same year, world population will have grown to nine to ten billion, so there is a real threat of global food shortage.

Locally, however, extreme weather events linked to climate change are already threatening food security in the poorest parts of the developing world. Detailed scientific analysis and fresh ideas are needed to solve both the acute, localised food security crisis right now, and the chronic, global one that we are drifting towards.

Vulnerability of smallholder farmers

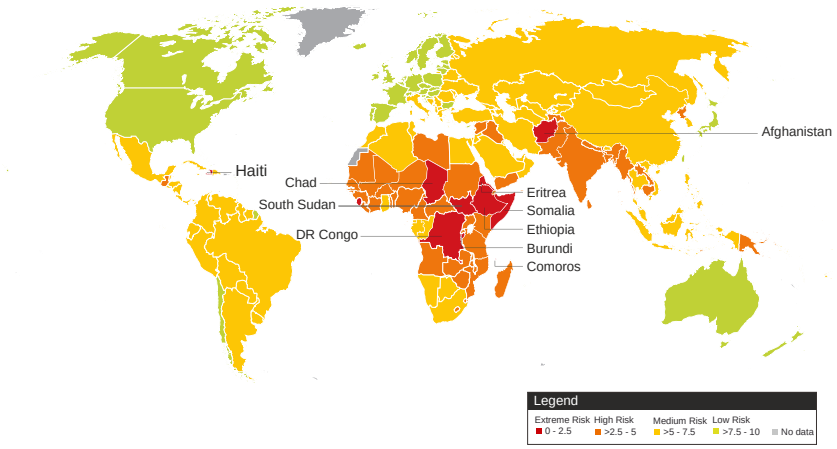
Across much of sub-Saharan Africa, large parts of the population are smallholder farmers whose livelihoods depend directly on their own agricultural production, both as a source of food for household consumption and for household income. As Celia Harvey from Conservation International in Washington, D.C., US, explained at a recent discussion meeting at the Royal Society in London, these farmers and their families are extremely vulnerable to the consequences of climate change.

Harvey and colleagues conducted a survey of smallholder farmers in Madagascar, where 75% of the population depends directly on agriculture for their livelihoods. The researchers found chronic and widespread food insecurity among the farmers, who typically cultivate an area of less than 2 hectares of rice, maize and cassava to supply for their families.

Due to a history of unsustainable practices, such as 'slash and burn' farming, much of the land in Madagascar is highly degraded and deforested. This is a threat both to the island's biodiversity (see Curr. Biol. (2012) *22*, R287–R289) and to the viability of farmers.

"The smallholder farmers are highly vulnerable to both climate- and non-climate-related risks to their agricultural systems, due to their high dependence on agriculture, high levels of poverty, poor infrastructure and lack of access to financial and technical support," Harvey explains. "Malagasy farmers obtain very low crop yields and farmers report that these yields have been declining over the last ten years due to a combination of land degradation and climate change." For instance, typical rice yields among the smallholder farmers surveyed were only 0.7–0.8 tons per hectare, much less than the 4–6 tons per hectare that could be achieved using improved practices and varieties.

Even in regular years, most farmers struggle to produce enough rice, their staple crop, to feed their families. Typically, they suffer chronic food insecurity for more than three months per year, before the new harvest comes in. As there are no formal safety nets, farmers cope with food insecurity by eating less food, selling their assets (particularly chickens) to gain income to buy food, borrowing food or money from relatives, or seeking outside employment to earn money to buy food. In addition, many resort



Food crisis: Food insecurity is a large and growing problem in many countries, especially in the tropics. (Map: © Maplecroft 2012. www.maplecroft.com).

Push–pull: Kenyan farmers trained to teach other farmers the push–pull approach pose with Lord David Sainsbury, who visited the project in 2010. Lord Sainsbury's Gatsby Charitable Foundation funded development and implementation of the push–pull project for 15 years (1994–2009). (Photo: Courtesy of the Push–Pull Programme (www.push-pull.net), International Centre of Insect Physiology and Ecology (ICIPE), Kenya.)

to collecting wild yams and to hunting animals in communal forests, which may lead to conflict with conservation concerns and further degrade the remaining forests.

Moreover, these farmers have to cope with frequent tropical cyclones and other extreme weather events, which further exacerbate their poverty and food insecurity. Of those households that Harvey and colleagues surveyed, 51% had been affected by a cyclone within the last five years, while 44% had been affected by floods and 68% by droughts. The cyclone season strikes at the critical point when food stocks are the lowest (the so-called 'lean season') and intensifies food insecurity further by destroying fields, homes and community infrastructure.

Most of the smallholders don't have much of a surplus to sell and thus very little money to buy any other products, says Harvey, but for those who can participate in trade, the market volatility (Curr. Biol. (2011) *21*, R795–R798) and the poor infrastructure, which makes it hard to get products to markets, pose additional threats. As climate change in Madagascar is expected to increase the frequency and severity of extreme weather events, Harvey says, urgent action is needed to reduce the vulnerability of smallholder farmers and to help them adopt adaptation measures that will make their systems more resilient to climate change in the future. "In Madagascar, as in many other parts of the developing world, efforts to reduce hunger and poverty will only be successful if there is a concerted focus on improving the livelihoods of smallholder farmers and reducing their vulnerability to climate change and other risks," Harvey concludes.

Pests and pesticides

In an attempt to improve their yields, farmers may resort to generous use of pesticides, but that can also backfire, as Paul Jepson from Oregon State University reports based on his experience in West Africa. "The use of pesticides in West Africa is broken," Jepson told the Royal Society meeting (which he co-organised), "as users have no knowledge of the pests they are supposedly fighting."

Jepson's studies in Senegal showed that the typical pesticide exposure of children working in the fields for two hours is so high that they should not be allowed to come back within three weeks. Practically, however, the children are forced to work in the fields every day and are exposed to serious health risks. "Human exposure in Senegal is completely different to all we know in Europe and in the US," Jepson said.

William Settle from the UN Food and Agriculture Organisation (FAO) in Rome is also concerned about this problem. In the Niger river basin in West Africa, he says, the water resources are severely threatened by pesticide misuse. Moreover the pesticides haven't even reduced the pests, as in some cases they have wiped out their natural enemies instead and thus enabled the pests to thrive.

Cotton farming is responsible for much of the pesticide use in West Africa, says Settle, and it acts as an 'open door' for pesticides, as products distributed for cotton may be inappropriately applied to other crops instead.

Educating farmers in the sustainable and efficient use of pesticides is an important priority. As part of the Integrated Production and Pest Management (IPPM) programme, the FAO has established Farmer Field Schools in the area, in which more than 100,000 farmers have participated already. Between 20 and 25 smallholder farmers meet once weekly for the full farming season, not only to learn what they need to know about the pesticides, but also to develop farming strategies adapted to the local conditions, their specific needs, and the economic context.

First results from Mali, Burkina Faso, and Senegal show that the participating farmers reduced their use of chemical pesticides by more than 90% and achieved yield improvements. They also increased their use of organic materials, such as compost and manure, which can help to maintain soil fertility.

New strategies

Innovations are needed to increase the yields of agriculture in sustainable ways. One recent innovation that has shown great promise is the push–pull system developed by the International Centre of Insect Physiology and Ecology (ICIPE) in Kenya together with Rothamsted Research in the UK.

The three main problems keeping productivity in sub-Saharan Africa low are the stemborer, the parasitic weed *Striga*, and loss of soil fertility. The push–pull system is an integrated approach to address these problems

simultaneously by planting suitable co-crops chosen from locally available plant species, says Zeyaur Khan from ICIPE.

To protect maize fields in Kenya from the stemborer, for instance, a border planted with Napier grass (*Pennisetum purpureum*) has proven highly efficient. This plant species attracts the stemborer but doesn't allow it to reproduce. Thus it efficiently pulls the pest out of the field it surrounds and neutralises it. In addition, the Napier grass can also serve as animal feed, provided it is harvested gradually, such that a functional ring of plants always remains in place around the field to be protected.

A second plant, the tick trefoil (*Desmodium*), can be used to fight the witchweed (*Striga*). Planted between the main crop plants, it releases a chemical that deters *Striga*. In addition, it also provides nitrogen fixation services, as it is a legume with root nodules.

The system has been adopted by thousands of farmers in Kenya already, with Barack Obama's grandmother being among the local people who promote its usefulness. The major challenge now is to expand it to millions of farms, so it can make a significant improvement to food security in sub-Saharan Africa.

A first step has already been made. "With a research grant from the European Union, we have now adapted the push–pull technology to the increasingly dry and hot conditions associated with climate change in Africa to ensure its long-term sustainability," Khan explains. "The conventional push–pull system has not been extended to drier areas of sub-Saharan Africa, and thus the new research has provided a relevant and effective agricultural innovation for cereal-livestock smallholders living in those areas."

Win–win: Both the black-breasted weaver and the grey-bellied cuckoo are 'winners' in that they thrive around high-yield agriculture, but due to the different shapes of their response curves, the weaver fares better with land sparing, while the cuckoo prefers land sharing strategies. (Photo: J.M.Garg http://en.wikipedia.org/wiki/User:Jmgarg1.)

Biodiversity trade-offs

The hotspots of food insecurity, where agricultural development is most needed, often coincide with areas where biodiversity is rich but under threat. Therefore, ecologists are trying to find out which kind of strategies can improve agricultural productivity without creating additional threats to wildlife.

Ben Phalan from the University of Cambridge, UK, highlighted that both the intensification and expansion of agriculture can be damaging to biodiversity. "Observing that intensification is harmful to wild species is not enough to tell us the best way to respond to this threat", he says. "Conservationists need to consider a range of options, including whether we should accept intensification in some areas if that's the best way to help reduce habitat loss elsewhere."

Phalan and colleagues have systematically analysed whether biodiversity is better served by high-yield farming on as little land as possible while protecting unfarmed habitats (land sparing) or by farming larger areas less intensively, leaving more opportunities for wildlife in the agricultural landscape (land sharing).

Studying bird and tree species in southwest Ghana and northern India, they measured the density of species as a function of crop yields on selected plots (Science (2011) *333*, 1289–1291). They distinguished 'winners' and 'losers' — species that are positively or negatively affected by agriculture, respectively. Both groups include species that would do better from land sharing than land sparing. These are characterised by density–yield relationships that bulge upwards, so have relatively high population density at low or intermediate yields. A larger number of species in both groups show the opposite effect, with low density at intermediate yields, and would therefore fare better with a land sparing approach.

The results from Ghana and India indicate that, to produce a given amount of food, land sparing would enable more species to persist than would land sharing or intermediate strategies. Phalan cautions that the results should not be generalised to other parts of the world, and also that increasing yields is no guarantee that land will be spared for nature.

"Our work suggests that land sparing, in some places, has a lot of potential in principle", he says. "For that potential to be delivered in practice, there is a need for explicit policies to make the connection between increasing yields and protecting or restoring natural habitats."

Ecosystem services

While researchers like Phalan try to balance out the interests of human nutrition and wildlife conservation, others use the ecosystem services approach (see Curr. Biol. (2011) *21*, R525–R527) to try and enrol nature in the fight for adequate food supplies for humans. Both Ferdinando Villa from the Basque Centre for Climate Change and Guy Poppy from the University of Southampton represented this approach at the Royal Society meeting.

Villa argued for an integrated approach that not only assesses the value of ecosystem services at their respective sources but also follows their flows towards the eventual users. Mapping sources, beneficiaries and the complex flow pattern between them, Villa's analyses are able to highlight 'trouble spots' where collisions of conflicting interests or changes of patterns could lead to problems.

Poppy, who also was a co-organiser of the meeting, leads a new research project called ASSETS (Attaining Sustainable Services from Ecosystems through Trade-off Scenarios). This project investigates two model regions at the forest–agriculture interface, one in Colombia and one in Malawi. The case studies cover around two million people, but the researchers believe that the results they obtain will be relevant to over 550 million people living in similar conditions around the tropics.

Specifically, the interdisciplinary research team wants to achieve a quantitative analysis of the interactions between ecosystems and the people who interact with them. The three main research areas are investigating drivers and linkages, crises and tipping points, and the science–policy interface.

With respect to policy, the researchers hope to make an impact on the food security in the areas concerned by improving the management of ecosystem services, by minimising risks, and by improving the integration between different levels of decision making.

Bleak outlook

Science is clearly essential in the bid to improve food security against the combined threats of population growth and climate change. However, if mankind fails to put an end to the ongoing rise in carbon dioxide emissions, even the best innovations may fail to avert catastrophic consequences.

Alex Scrivener from the World Development Movement sees a bleak future: "The continuing inaction on the part of rich countries on climate change, which was demonstrated at the Doha climate conference, threatens the food security of millions of people around the world," he commented. "The pathetically inadequate pledges being put forward by the UK and other developed countries almost guarantee a world in which we will see between 4–6°C of warming, a situation which will mean sharp drops in crop yields in some of the world's poorest countries. By failing to cut emissions, we are condemning whole swathes of the planet to famine."

Michael Gross is a science writer based at Oxford. He can be contacted via his web page at www.michaelgross.co.uk

Q & A

Malcolm Bennett

Malcolm Bennett is Professor of Plant Science and Director of the Centre for Plant Integrative Biology (CPIB) at the University of Nottingham. After becoming enamored with DNA as a teenager, he studied molecular biology and biochemistry at UMIST (now part of the University of Manchester). During his postgraduate studies he developed a passion for the 'hidden half' of plant biology, root development. He later spent time as a NATO Fellow at the University of Arizona in the Feldmann lab, which pioneered gene tagging in the model plant Arabidopsis thaliana*. His studies on the hormonal control of root growth and development led to the identification of the first auxin transport protein described in plants. Since 2005, he has embraced systems-based approaches to successfully address several of the oldest and most recalcitrant questions in plant biology. This multidisciplinary approach has recently helped overcome the single biggest impediment in root biology, the ability to non-invasively image roots growing and developing in soil.*

What turned you on to biology? I originally found the way biology was taught at UK Schools in the 1980s very dull and largely organism-focused. Then one day in my biology class, I found a pamphlet in a book cupboard about the *E. coli lac* operon. I was immediately struck by the elegance of the molecular circuitry that controlled the *lac* operon's induction and repression. This was the kind of biology I could understand and appreciate! Later, with the help and encouragement of my university tutor Professor Paul Broda, I spent successive summer vacations working in research labs studying fungal, cancer and plant molecular biology. The latter experience convinced me that, whilst a much smaller field than human, animal or microbial sciences, plant research had the potential to have a larger global (and humanitarian) impact.

Do you have a favorite paper? The *Arabidopsis* genome sequence (The *Arabidopsis* Genome Consortium, *Nature,* 2000), since it revealed the genetic make-up of plants and clearly demonstrated that they are not 'green animals'. Instead, plants as multicellular organisms have evolved completely different signaling solutions. For example, plants do not contain large repertoires of G-protein coupled or tyrosine kinase receptors in their genomes. In contrast, they have evolved novel classes of receptors, some based on the ubiquitination machinery, where hormones bring together the receptor and a labile transcriptional repressor protein, to activate hormone-responsive gene expression. This difference is likely to reflect that, unlike animals, plants employ small signaling molecules due to size constraints imposed by their cell walls.

What is the best advice you've been given? I've benefited from good advice throughout my career, but 4 statements stand out in my memory. First, as an undergraduate at Manchester, Professor Steve Oliver once told me that, as a geneticist, "It's better to be smart and lazy, than dumb and hard-working". He has been proven right again and again in my career. 'High throughput' reverse genetic studies (*i.e.* sequence-to-mutant) have often proved frustrating, whereas elegant forward genetic screens (*i.e.* mutant-to-sequence) have always reaped new biological insights. Second, as a postgraduate student at Warwick, Professor Mike Lord once complained about a high-profile speaker presenting "technology in search of biology". The need to focus on the biological question in hand, and not become enamored with the technology employed, has remained with me to this day, since one is perennial, whilst the other is often quickly superseded. Third, about to return to the UK and set up a new lab, my US boss Ken Feldmann gave me three pieces of advice, "Focus, focus, focus". If only I'd heeded that advice as a young PI it would have saved me so much trouble and wasted effort. Ironically, later in my career, openness to the possibilities through other disciplines has proven very helpful in addressing recalcitrant problems in my own research area. Finally, I am not by nature a finisher, but I have learned to be, after Professor Don Grierson at Nottingham wisely pointed out to me that, "If a piece of work hasn't been published, it hasn't been done."

What is your greatest ambition? Like almost every other scientist, I would like new insights generated from my