Future-proofing with advanced and emerging technologies and tools

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ABSTRACT

Ongoing contributions of agriculture to human health and well-being face major risks. Extreme poverty *per se* and ineffective policies for development, trade and regulations are the largest risk multipliers, with abiotic and biotic stresses being the major risk drivers. Prevention, effective response, and innovation are the key risk mitigation factors. Tools and technology for 1) monitoring, modelling and predicting risk emergence, 2) deploying, tracking and optimising existing solutions, and 3) on-going innovations for better tools and solutions, are keys to future-proofing our agricultural system. I propose focusing on overall water-use efficiency as the normalising basis for quantitative tracking and prioritisation of progress and setbacks. Yeildgap.org is an excellent resource for tracking realised harvest vs water-limited potential harvest. Poor soil fertility in developing countries and pests/pathogens everywhere are the major limitations on agriculture using existing best practices. Soil fertility can be readily solved; the future will be limited primarily by pests and pathogens and increasing abiotic stresses. Recent case studies from Africa illustrate the situation. Maize lethal necrosis virus erupted suddenly in East Africa and exposed a vulnerability in the local seed system which, once understood, was then remedied. Cassava mosaic disease is an on-going and spreading problem that threatens much of Africa's cassava crop. Despite excellent progress in tracking, modelling and development of solutions, it remains a major threat, due to slow progress in deployment of new resistant varieties and cooperation within and across country borders to contain the outbreak. New strains of wheat rust have emerged in eastern Africa and spread around most of the world. Deployment of single resistance genes has led to progressive loss of their effectiveness, complicating efforts to build a more durable resistance package. Molecular efforts to splice together multi-gene packages, and using synthetic biology to create new resistance genes not found in germplasm collections, promise a more robust and durable solution.

I want to start with a normalising factor for looking at just how big are the opportunities to make progress, how big are the risks, how big is the progress we are making, and I propose to use water-use efficiency as the overall basis.

In this talk I refer to nine websites. First, Global Yield Gap Atlas (yieldgap.org), looks at water-use efficiency in a very interesting way. We can click on the atlas, and 'Rainfed wheat', and Australia on the map (Figure 1), and look at the underlying data which show 'yield potential' for the given amount of water that Australia receives, 'yield actual' for the yield Australia actually gets, and 'yield

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This record was prepared from the transcript and illustrations of the Zoom presentation.

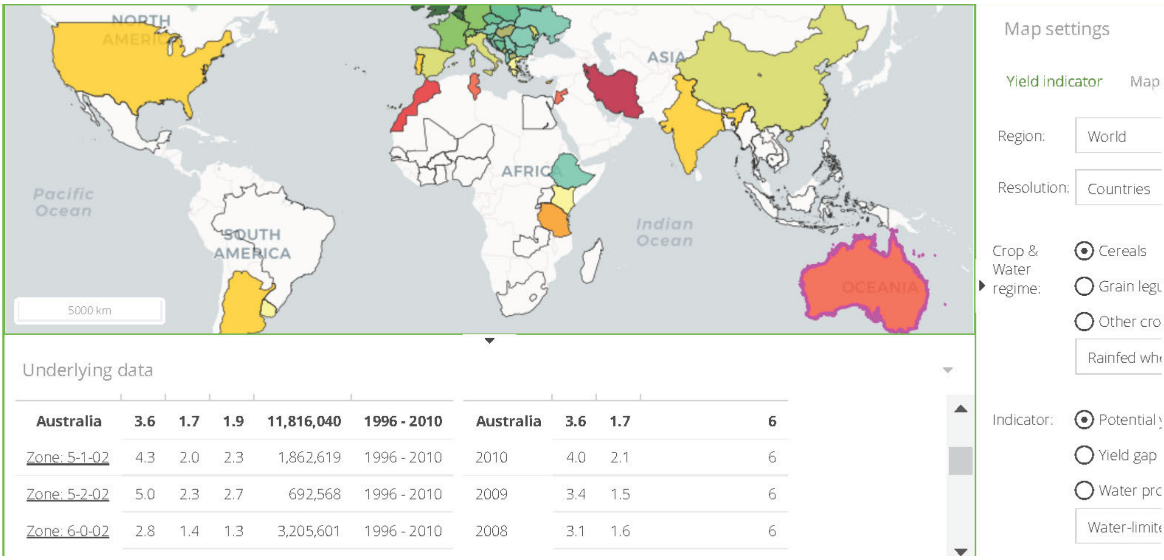


Figure 1. Data for Australian rainfed wheat at https://www.yieldgap.org/gygaviewer/index.html

gap' for the amount of yield potential that Australia does not realise. According to these projections for rainfed Australian wheat, the realised yield is less than half of the water-limited yield potential, which means there is huge headroom for improving the productivity and efficiency of wheat production – and the same is true essentially for all crops in all countries. I should point out that some or most of the gap is not economically feasible to close, using current technologies.

Before I talk about work aimed at closing the gap, I want to mention work aimed at making the gap *bigger* by raising the ceiling of what is possible. I should say the reason agriculture is water intensive is because plants buy carbon dioxide, paying for it with water, through passive diffusion of water vapour out of stomata. Passive diffusion of carbon dioxide into stomata is how plants get carbon on which to grow. The biochemistry and physiology of photosynthesis determines the exchange rate of water for carbon. The RIPE project (Realising Increased Photosynthetic Efficiency; Figure 2) is looking to make the gap bigger by improving the amount of harvest that is possible for a given amount of water by making carbon dioxide cheaper in terms of water price for plants. A variety of methods were first hypothesised 'in silico' (that is, by computer simulation) and they are now being experimentally pursued. I want to mention partners in Australia in this effort: Jose Barrero, TJ Higgins (our Chair for this session), Tori Clarke, Susanne von Caemmerer, and Dean Price, the last three being at the Australian National University. They are all partners in this, looking at making the gap bigger.

Of course, the other part of this problem is how to make the gap smaller, not by raising the ceiling but by closing the gap between what is actually harvested and

About RIPE (/objectives/our-story)

Our Crops (/objectives/our-crops)

Institutions (/about/institutions)

Objectives (/objectives)

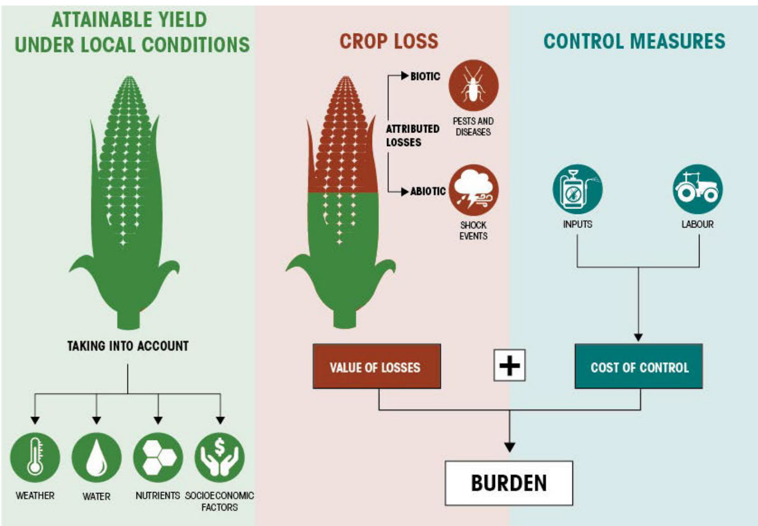
Modeling Photosynthesis (/objectives/modeling-photosynthesis)

Relaxing Photoprotection (/objectives/relaxing-photoprotection)

Modeling Photosynthesis

Photosynthesis—the 170-step natural process in which plants use sunlight and carbon dioxide to grow—is one of the most basic, yet incredibly complex, processes in biology. It is also inefficient. Approximately only 5 percent of the energy from sunlight is converted into plant growth and even less into the parts of the plants that we eat. Scientists speculate that photosynthesis could be transformed if they could find which steps out of the total 170 can be tweaked and modified to make the process more efficient. With the rapid increase in technological advancements, computers can simulate photosynthesis in a real-life environment. These simulations provide a realistic representation of the entire process and can show what happens to plants if variables were to be manipulated, such as light energy distribution by altering the angle of leaves, adding additional cellular machinery, or changes in climate. By using mathematical equations in the computer system, it is possible to see which potential combinations of changes in photosynthesis would lead to the most crop growth and highest yields.

Figure 2. About the RIPE project, at https://ripe.illinois.edu/index.php/objectives/modeling-photosynthesis



Crop and loss | **Burden** | **Attribution of loss** | **Scope**

The crops and loss theme will focus on determining how much crop yield is being lost at the global, regional or national scale. The process will identify where crops are being planted and how much is being harvested (actual yield).

Figure 3. 'The Global Burden of Crop Loss initiative', at https://croploss.org/our-approach

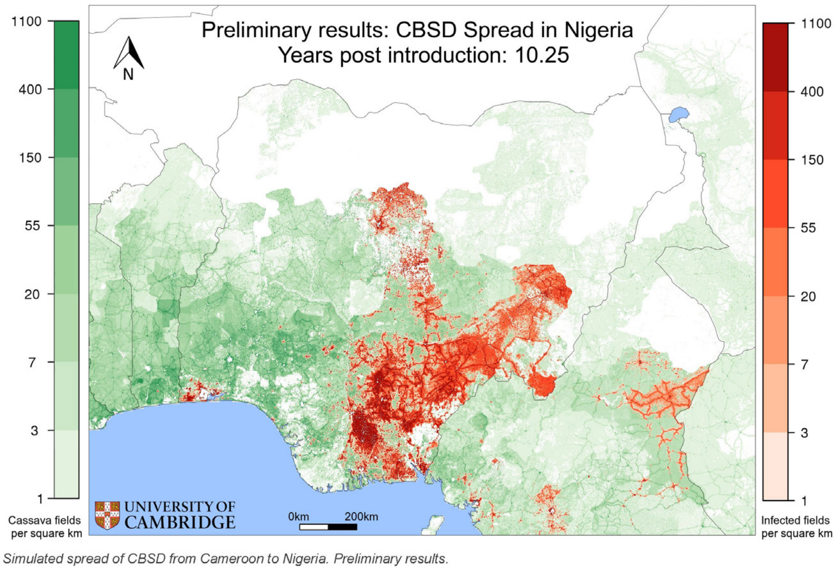


Figure 4. Screen grab from video of a simulated future spread of cassava brown streak disease (CBSD) in Nigeria, at https://plantepidemics.github.io/

what could be harvested. And the group behind croploss.org (Figure 3) is looking at the size of some of these gaps in the global burden of crop loss.

Some stressors are abiotic, and some of them are biotic. I now focus on three examples of biotic stressors that are major contributors to crop losses.

Cassava brown streak disease

My first example is an African virus disease of cassava, and this illustrates the use of technology in both monitoring and predicting and modelling the epidemiology and spread of cassava brown streak disease (CBSD). The video at University of Cambridge webpage https://plantepidemics.github.io/ simulates what the outbreak might look like (Figure 4) when CBSD gets into Nigeria. Currently it is moving westwards from East Africa. There are serious efforts underway to anticipate and combat this spread, as well as technological improvements to invent better ways to control it.

One of the groups working on CBSD is WAVE (Central and West African Virus Epidemiology for Food Security) which was started by Justin Pita. The WAVE Project is described at the WAVE website (https://wave-center.org/).

Another group, the VIRCA (Virus Resistant Cassava for Africa) Plus Program, is working on a biotech solution to the cassava brown streak disease (Figure 5). That work is based at the Donald Danforth Plant Science Centre in St Louis, Missouri, and partners around the world including with the National Crops Resources Research Institute, Uganda, and the Kenya Agricultural Research Institute. They aim to engineer both virus resistance and micronutrient density increases in cassava. Their use of siRNA gene constructions in the lab has been tested in the greenhouse and is now being field tested in Africa, on the way

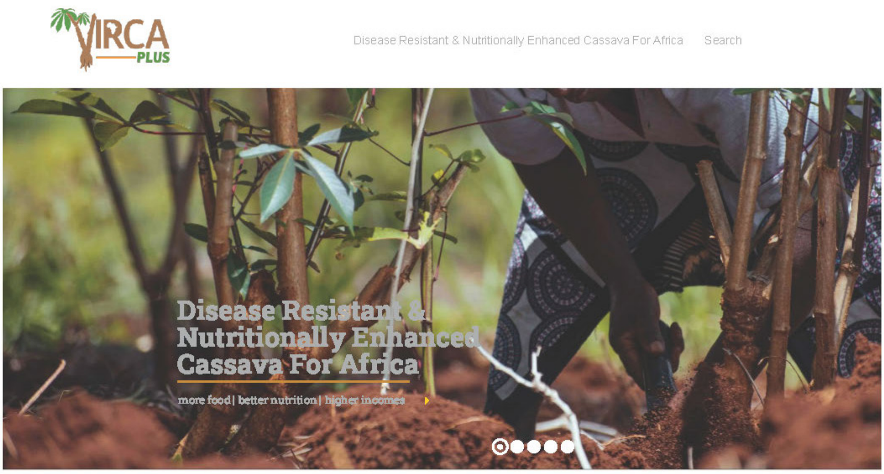


Figure 5. Home page of the VIRCA Plus Program, at https://cassavaplus.org

to being combined with conventionally sourced other virus resistance genes in cassava, and then field tested for final varietal approval before deployment in Kenya and Uganda and other countries. The project has taken more than 20 years to get this far, and it is great to see it now in the field, almost ready for use in Africa.

Wheat rust

My second example is wheat rust, which Prabhu Pingali already mentioned.

The experience involved in the Borlaug Global Rust Initiative at Cornell University spans the whole world (see Figure 6). There are collaborators in Australia who are, and have been, a key part of the effort against wheat rust. This is focused on conventionally sourced resistance genes being bred into modern cultivars, and

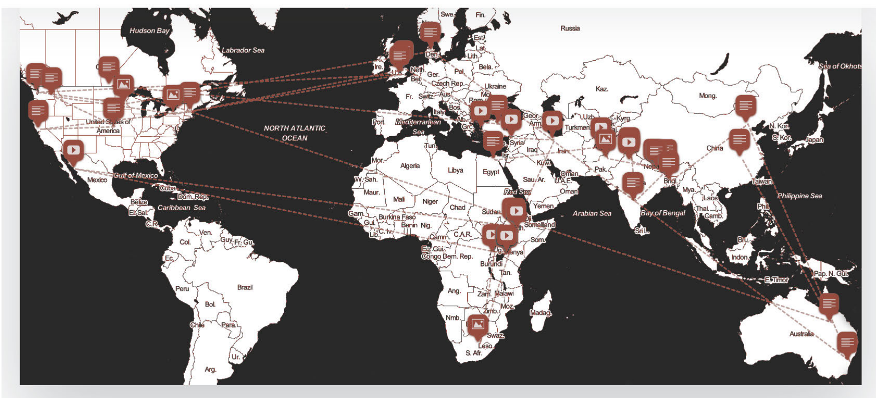


Figure 6. 'Experience the BGRI interactive story map' webpage at https://bgri.cornell.edu/about-bgri/

then deployed ahead of the virulent strains of rust. As Prabhu showed, those virulent strains are spreading around the world.

In addition to using the conventionally sourced breeding and doing it faster and deploying it ahead of the waves of new disease, the 2Blades Foundation, of which I am a Board Member, is also looking at stacking genes together. The strategy is to stack up to five resistance genes in a gene package and introduce them into particular wheat varieties (see https://2blades.org/projects-and-technology/projects/1/). Then it will be breedable and heritable as a single locus, making the breeding and combining with other efforts much more possible. Quite a few Australian collaborators are involved in this synthesis effort. And beyond combining and packaging multiple genes in one locus, 2Blades is also working on synthetic genes that build on the knowledge of how the host and pathogens interact: aiming to create genes that will recognise new virulent strains of the fungus. The new genes would be introduced into wheat so it can become resistant – which should be much quicker than going back and looking for something in nature that was there and is not currently being used.

Insect attack on cowpeas

Finally, cowpeas. The success reported at AATF (African Agricultural Technology Foundation) webpage below (Figure 7) includes work of the Chair of this session, TJ Higgins. The project this year (2021) advanced a transgenic Bt cowpea through to good tests in the growth chamber, and successful field tests in Africa. It is on its way to final varietal approval, and then deployment to farmers in Nigeria.

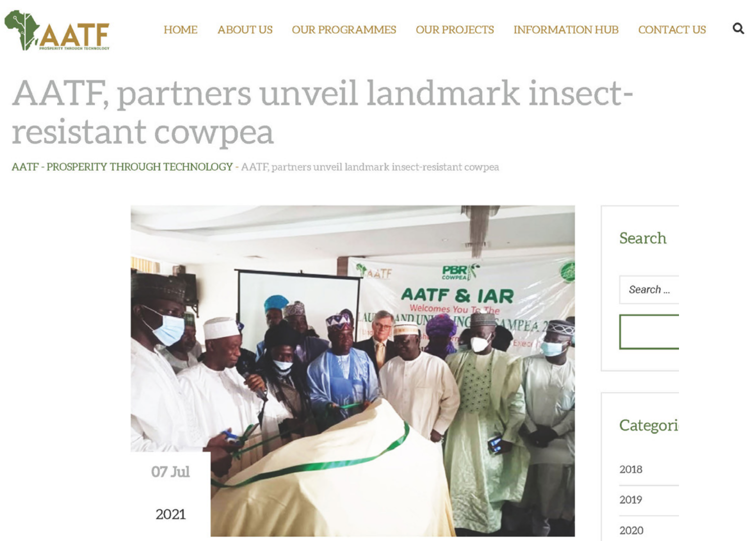


Figure 7. aatf-africa.org/aatf-partners-unveil-landmark-insect-resistant-cowpea/

Dr Rob Horsch recently retired from the Bill & Melinda Gates Foundation which he joined as a deputy director in November 2006 to develop and lead the science and technology initiative of the agricultural development program. He recruited and managed a team of program officers and other staff that made and managed a large and diverse portfolio of research and development grants aimed at improving the productivity of smallholder farmers by improving the crops that poor farmers raise, and poor consumers eat. He currently serves on the Board of Directors of the Foundation for Food and Agricultural Research and the 2Blades Foundation, and as an Adviser to the Global Commission on Adaptation and to the Global Farmer Network.

Rob is a leader in the effort to create agricultural technologies that help improve yields and incomes for farmers around the world. He joined Monsanto in 1981 and led the company's plant tissue culture and transformation efforts until 1995. In that capacity, he contributed to the development of the Bollgard, Yieldgard, and Roundup Ready traits in broad use today and directed an expanding research group to apply genetic transformation technology to many important crops, including potato, tomato, cotton, soybean, corn and wheat. From 1996 to 2005 he led the company's programs for International Development Partnerships with responsibility to help smallholder farmers in developing countries gain access to better agricultural products and technologies.

Rob received his PhD in Genetics at the University of California, Riverside, in 1979, and then conducted postdoctoral work in plant physiology at the University of Saskatchewan. He has served on the editorial boards of several leading journals in the plant sciences and as an adviser to the National Science Foundation and the Department of Energy. He served as a member of the Millennium Development Goals Hunger Task force and has been active in international agricultural development projects for the past 25 years. He was awarded the 1998 National Medal of Technology by President Clinton for contributions to the development of agricultural biotechnology.