THINK PIECE

# Game-changing technologies in agriculture

Global Food Security
Sustainable, healthy food for all

# Contents

# Introduction

The UN's Food and Agriculture Organisation has estimated that 60 % more food per year will be demanded by 2050. Putting this in context, in just a 35 year period the earth is being tasked with producing more food than it has in the last 2000 years combined. Either we find very clever ways of sustainably producing more food on the same area of land, or we need to demand less. In reality we need to do both.

Whilst there are no silver bullets for producing enough to create global food security, it is clear that new technologies have a central role to play. One of the game changers of the past was the introduction of semi-dwarf varieties of cereals that channelled the crop's energy into seed production rather than height, and when combined with improved irrigation and fertilisers resulted in more than a doubling of yields in much of the developing world. This was the green revolution.

However, sub-Saharan Africa, which missed out on the green revolution, did not have large increases in agricultural productivity and this has resulted in persistent hunger and an increase in the land used for food production. Whilst the green revolution created environmental costs through intensification, the lack of a green revolution in sub-Saharan Africa has led to the expansion of crop land to keep up with production, creating another form of environmental cost through land conversion.

What is now needed is a new green revolution but without the associated environmental impact – this is one of the challenges facing researchers today working on the 'sustainable intensification' of agriculture. Increasing yields on existing land, whilst mitigating environmental impact, reduces the pressure on bringing new land into agriculture, and the huge environmental costs this brings.

New technologies will play an important role given the magnitude of the challenges for food security in the coming decades, alongside measures to address demand such as reducing waste and changing what we eat. An essential part of any new innovation is engaging the public at an early stage – something the Global Food Security (GFS) programme is supporting.

# Game-changing technologies

Game-changing technologies can be defined as those which have the potential to be transformative and revolutionise the way we do things. They are sometimes also called 'disruptive innovations'. The most successful technologies stem from a clear problem that needs addressing, rather than beginning with a technology and finding a problem to address later down the line.

These technologies often require researchers from academia and industry to work together. A 'food systems' approach may help identify the leverage points where transformation can be achieved, and collaboration with industry will help ensure the technology is developed in the way that it is most needed. A creative environment is essential, that enables good communication between sectors and disciplines.

Sometimes the technologies and knowledge required to solve certain problems already exist and just need to be adapted from other sectors. This can be enabled by the development of a new platform technology. Who, 30 years ago, would have predicted the things we can now do with a mobile phone, and how access to mobile communications could change the way we live?

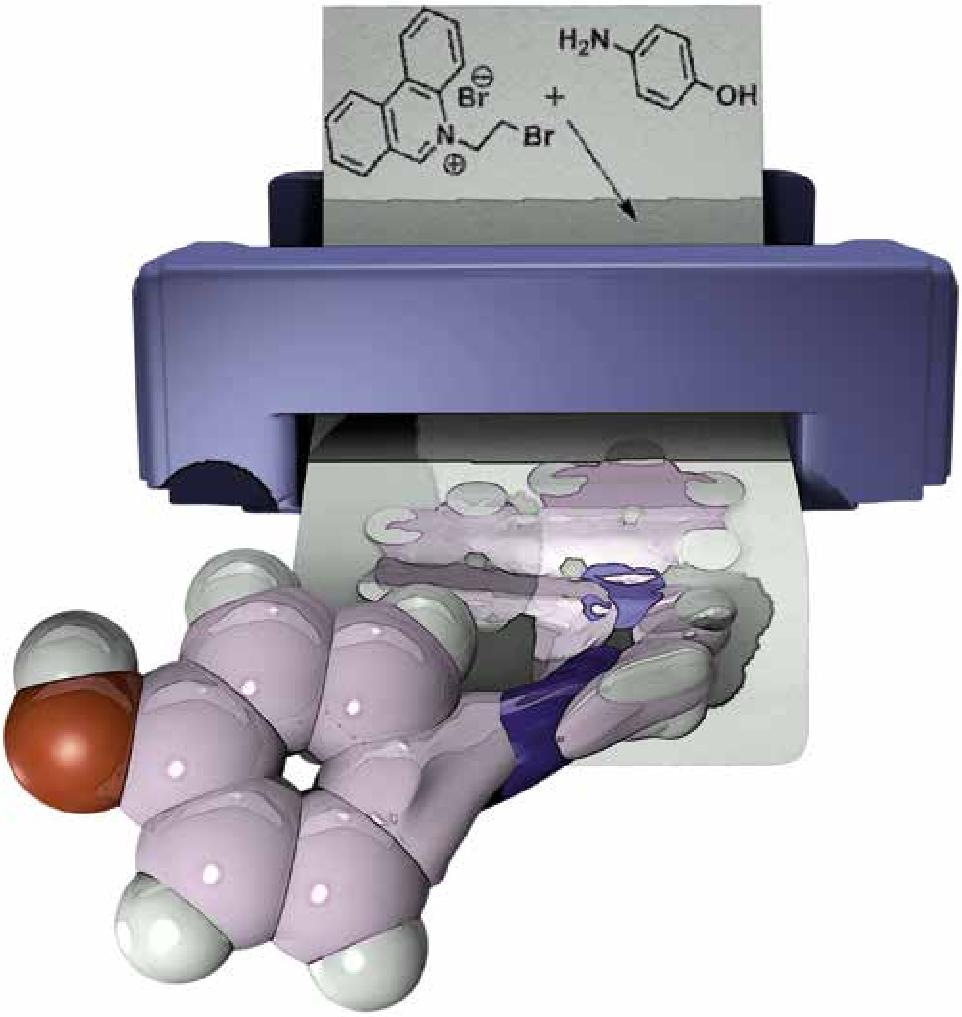
The development of new technologies is taking place in many areas of agriculture. The areas highlighted in this document are ones that have a strong disruptive potential, with significant impact in the next decade. This think piece summarises the outputs of a GFS programme[1] workshop on game-changing technologies. GFS brings together the major UK public sector funders of food-related research to take a coordinated and collaborative approach to tackling the food security challenge.

# 3D printing for custom chemicals

3D printers have the potential to revolutionise agriculture, allowing the production of chemicals (such as herbicides, pesticides and veterinary medicines) on the farm as and when they are required. This potential game changer requires three components; software apps, a 3D printer and chemical 'inks'.[2]

The technology, which is being developed by the University of Glasgow, is focused around the production of bespoke reactionware. A small vessel made from silicone acts as a miniature chemical manufacturing plant, holding chemical reactants before bringing them together. This vessel itself is produced by the 3D printer with the instructions provided by a downloadable app, and it is possible for a catalyst to be incorporated into the vessel material to speed up the chemical reactions that will take place within it. The chemical reactants (inks) are then dispensed (printed) into the vessel by the 3D printer, using instructions from another app, where they react to produce new chemical compounds.

This relatively inexpensive technology has the potential to transform agriculture, allowing highly specific chemical inputs to be produced on location and in the quantities required, wherever you are in the world.




Lee Cronin, University of Glasgow

# Green ammonia

Frank Peters/ Thinkstock

Producing ammonia from renewable energy sources has the potential to considerably increase the sustainability of fertiliser production in the future. Currently, ammonia production uses over 1-2% of the world's energy and is responsible for 1% of $CO_2$ emissions and 3-4% of total EU gas usage.

Generating ammonia through electrochemical reactions instead of the Haber-Bosch process, using renewable energy, could allow fertiliser to be produced in a carbon-free way. The Haber-Bosch process uses natural gas (methane) as a source of hydrogen and large amounts of energy to maintain high pressures and temperatures.

In the electrochemical reaction, hydrogen is produced by splitting water which is combined with nitrogen in the air on an electro-catalyst to produce ammonia. The process requires relatively low energy and is powered by renewable electricity from wind or solar.

This technology is currently being developed by Siemens[3] for multiple purposes, including as a way of storing renewable energy, as a potential transport fuel, and as a low-emission way of producing ammonia. There are a number of challenges to overcome, including operating in a low pressure environment and the intermittency of energy supply from renewable sources.

For farmers in developing countries who are often off grid and away from the major distribution routes for fertilisers, this technology has the potential to provide them with an in situ source of ammonia, which could dramatically increase their yields.

# Aquaponics

Aquaponics could provide a way of producing food locally in a sustainable way as the world becomes more urbanised.

The technology combines hydroponics (growing plants in water without soil) with fish farming to create a closed loop system.[14] The fish are kept in tanks and fed fish food - often Tilapia is used because it is herbivorous and does not need to be fed wild-caught fish. Their excrement goes into the water, making it nutrient rich. This nutrient-rich waste water is pumped to the roots of the plants through a biofilter, which converts ammonia into the nitrates that the plants need. The nutrients are then taken up by the plant, which purifies the water. The purified water is then pumped back to the fish, and the cycle continues.

The inputs are fish food and energy for the pumps, water heaters and efficient LED lights. As the water is fed directly to the roots of the plants and then recirculated to the fish tanks, aquaponics uses much less water than traditional agriculture. This low energy, low water-use, vertical agriculture system provides an environmentally conscious way of growing food and is especially suited to cities. Aquaponic and hydroponic farms are often based in disused spaces such as warehouses and underground tunnels.[15]

The major crops being grown in this way are salads, microgreens and herbs, which are produced alongside fish, including species such as rainbow trout. [16]
Given that the world will be 70% urbanised by 2050 and there is by good approximation no new land for agriculture, this could provide a game-changing and efficient way of producing local fish and vegetables, making the best use of available land.

Plant Chicago, Flickr

Anguskirk, Flickr

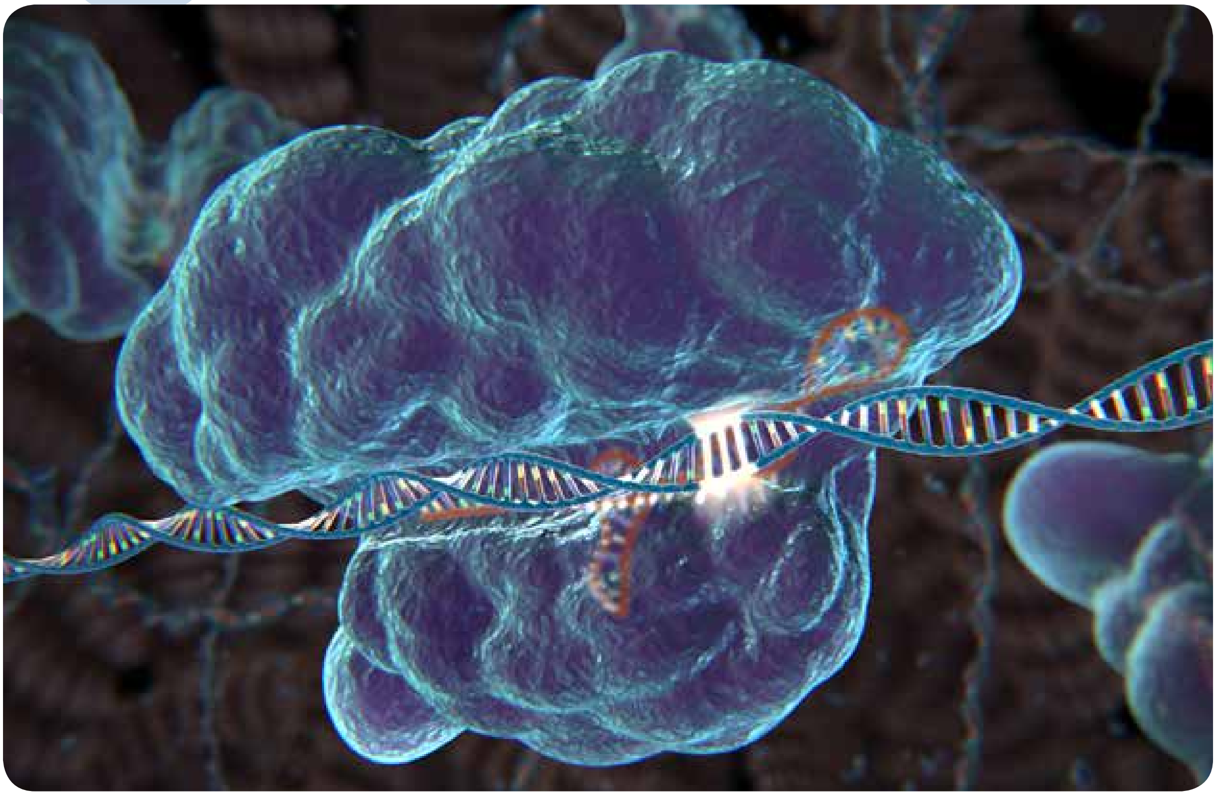
# Sentinel plants

Sentinel plants act as indicators of biotic or abiotic stress in cropping systems, by providing an early signal such as changing leaf colour in response to a stress event. These plants can provide early warning of new and emerging pests and diseases, nutrient deficiencies, or changes in soil conditions. An example of sentinel plants in action is rosebushes planted in vineyards which show earlier symptoms of fungal diseases compared to grapes, allowing for mitigating action to be taken.

Sentinel plant networks are also being developed[7] which allow for surveillance on national and international scales to identify global threats from pests and diseases at an early stage. This includes use of sentinel plants in ports, where pests and diseases are likely to enter a country.

Further work is required to understand the underlying biology behind these plants and how physical signals are linked to what the plant looks like. High throughput plant phenotyping is being used to identify desired traits in a range of environmental conditions, and when combined with genetic engineering could provide a new suite of sentinel plants for the future.

# Genome editing


McGovern Institute for Brain Research at MIT

A new technology called CRISPR now allows scientists to edit genomes with unprecedented precision, in an efficient and flexible way. The system consists of a strand of RNA that acts like a sat-nav to find and lock onto a gene of interest, and enzymes that act like molecular scissors to cut out the DNA at that location. The genome can then repair itself or a new gene can be inserted into the open space.

CRISPR technology could make genome editing an affordable option for both crops and livestock. The technology is already being used to infer disease resistance in wheat, rice and tomatoes; produce disease-resistant pigs and goats; and enrich sweet oranges with vitamins.[9, 10, 11,12]

As threats to agricultural production grow, tools such as these will allow access to crops and animals that are more resilient to extreme weather or new pests and diseases.

One challenge for regulators is that it will become increasingly difficult to tell the difference between a crop or animal that has been genome-edited to one that has been produced through conventional breeding. In addition, under existing GM rules which relate to organisms that have been engineered using bacterial or virus DNA, not all crops made by genome editing would require regulation. On the one hand this opens the gateway to innovation, but on the other hand the lack of regulatory oversight could lead to public distrust.

One further use of CRISPR technology is gene drives, which can channel a genetic change throughout a wild population over many generations. A gene drive allows a mutation made by CRISPR on one chromosome to copy itself to its partner in every generation, so that nearly all the offspring will inherit the change. Theoretically this could be used to eradicate weeds, pests or diseases, but there are concerns that large-scale changes to a population could have unintended consequences, such as the emergence of other pests or effects on predators higher up the food chain.

Genome editing is a developing technology but one that offers game-changing potential for agriculture in the future.

# Remote sensing and the internet of things

Remote sensing technologies allow farmers and other stakeholders to make management decisions based on datasets at the landscape level, taking into account soil types, water table depth, land coverage, resource use, ecosystems data, pests and diseases and weather. These data can come from sensors positioned across the landscape or from satellites, but there is increasing scope to use Unmanned Aerial Vehicles (UAVs) or drones to monitor local land use in real time and to ground truth satellite information.

Gabriel Onorato, Soil Science, Flickr

The field of sensors is booming, with the advent of wireless or bluetooth charging capability, meaning they can be powered remotely. Sensors are an integral part of a new approach called the 'internet of things', where data from different internet-connected devices is processed in real time through cloud computing, to determine the best course of action in response to changing conditions.[5]

Recommendations could be sent to a farmer's smartphone or tablet through a notification, and this could be as simple as recommending that the farmer irrigates immediately. A straightforward user interface as a front end to complex data sets and real-time analysis will make this game-changing for farmers. In the future it is likely there will be a move to automated decision-making, where the best course of action is automatically implemented via an internet-connected device, using the latest precision agriculture technologies; for example a small on-farm robot, that is able to understand its surroundings using imaging and satellite technology, automatically zapping a weed with a laser.[6]

By applying spatial and timely inputs farmers will be able to farm more economically, enhancing yields, reducing waste and minimising environmental impacts.

# Hyperspectral imaging with smartphones

A new low cost hyperspectral imaging sensor for smartphones could provide a simple way to detect the early onset of crop diseases and substantially minimise crop losses in developing countries. The sensor is currently being developed by Barefoot Lighting Ltd and the University of Manchester.[4]


Barefoot Lighting

The technology would enable extension workers to scan plants for disease signals which would be referenced against a database of possible diseases, and they could then advise on interventions needed. If new diseases were found, extension workers could also add these to the database, simultaneously building up the database and providing an early warning system. Collecting data in this way can create a high-value dataset which could be marketed to agronomy companies, with the revenue generated being used to make these technologies more widely available to those in low-income countries.

Further research is looking at using hyperspectral imaging (in combination with other imaging technologies) to identify plant disorders such as nutrient deficiencies; to detect insect disease vectors such as white fly which carries mosaic virus; to obtain real time information on below-ground water and nutrient flows; and to detect sea lice in salmon and trout for the aquaculture industry.

# Prescription farming

Prescription farming is a way of integrating data about a farm and its environment to determine what will grow best in different parts of a field, and then planting different seeds across the field as required.

Monsanto is leading the way in this area with a new prescription planting system called FieldScripts.[13] It has developed a database that maps the soil and weather data for all of the farms in the US, using climate data, remote sensing and cartographic methods. The system combines this with Monsanto's library of hundreds of thousands of hybrid-seeds, and terabytes of data on their yields.

Precision planters, which can steer themselves via satellites, can then use this data to plant a field with different seed varieties at different depths and spacings, according to the unique local environment in a given part of a field. In this way it is carrying out bespoke diagnostics and prescribing the best course of action at a micro scale.

Early results have shown that this system can increase yields over a two year period by 5% – an increase that is not currently possible through other means.

Seed companies believe this data-centric approach could eventually increase America's maize yield by 25%.

# Conclusion

There are many new and exciting technological breakthroughs being made and this think piece just scratches the surface. If we are going to feed a growing population it is clear that we will need to use all of the tools in the toolbox, and provide a supportive environment to enable the development of new ones.

Cutting-edge technologies can bring huge benefits but these will only be realised if society is involved from the outset through two-way dialogue. GFS is taking such an approach, facilitating the development of new technologies whilst ensuring there is public engagement throughout, to help meet the food security challenge.

T. Samson/CIMMYT

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