FEED THE WORLD

How Exponential Technology Can Create an Abundant Future

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Contents

FEED THE WORLD

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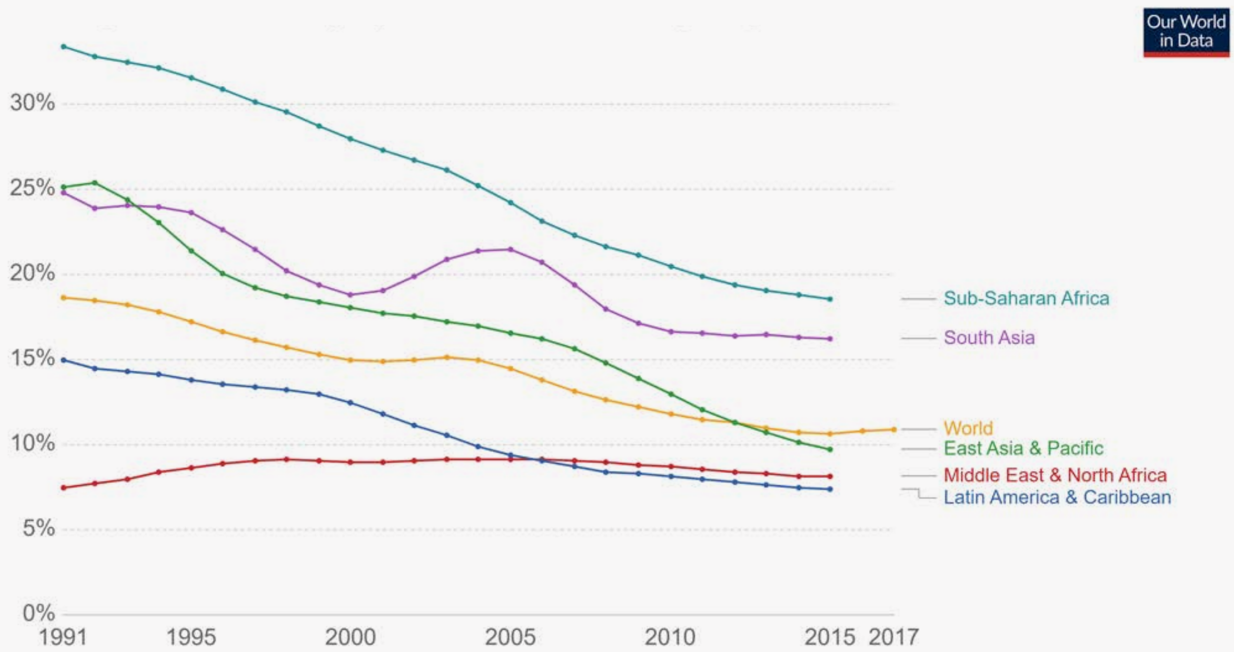
Introduction

Human history has been marked by the uneasy coexistence of feast and famine.

More than 113 million people across 53 countries experienced acute hunger requiring urgent food, nutrition and livelihoods assistance in 2018, according to the **Food Security Information Network**. Food is one of the 12 large-scale health and development problems Singularity University is helping to empower a global community to solve. Based on the United Nations Sustainable Development Goals, we call them **global grand challenges (GGCs).**

It's encouraging to witness the overall decline of undernourished populations over the years (see table below), as well as the rapid emergence of exponential technologies driving exciting new initiatives that bring us ever closer to terminating global food shortages. Although the situation has improved considerably over time, hunger and malnutrition are still part of the human existence, proving to be an intractable problem.

In this ebook, we'll look at how exponential technologies are revolutionizing the agriculture industry and the related implications for the global supply chain. We'll explore some of today's most promising to efforts to end hunger that leverage AI and robotics. And we'll highlight the progress and trends we're seeing and explore how we might continue moving toward a world where no one faces food insecurity.



Source: UN Food and Agriculture Organization (FAO)
Note: Developed countries are not included in the regional estimates since the prevalence is below 5%.

Share of the population that is undernourished

This is the main FAO hunger indicator. It measures the share of the population that has a caloric intake which is insufficient to meet the minimum energy requirements necessary for a given individual. Data showing as 5 may signify a prevalence of undernourishment below 5%. Regional aggregations are based on World Bank regions and exclude high-income countries. They may therefore differ from UN FAO regional figures.

IMAGE SOURCED FROM OUR WORLD IN DATA

Increasing Agricultural Productivity

Agricultural technologies are progressing at an accelerating rate. It's necessary now, more than ever, to apply innovation and exponential technology to:

- Sustainably feed booming populations across the developing world
- Address the growing challenges of climate change
- Solve inefficiencies that result in spoilage and distribution issues

Large-scale solutions include smart equipment automation and satellite imagery. Emerging indoor solutions that have the ability to increase agricultural productivity include vertical farming, to laboratory-based gene editing, to culture-grown meat. As these technologies are developed and deployed, the power of technology may bring about the next agricultural revolution, giving farms of the future an entirely new appearance.

Automation on Farms of the Future

Picture yourself on a farm of the future. Swarms of drones buzz overhead, while robotic vehicles crawl over the earth's surface. Orbiting satellites snap high-resolution images of scenes far below. Not one human being can be seen in the pre-dawn glow spreading across the land.

Every phase of farm operations—from seed to harvest—may someday be automated, without the need to ever get one's fingernails dirty. In fact, what once felt like science fiction is already being engineered into reality.

Today, robots empowered with artificial intelligence (AI) can zap weeds with preternatural precision, while autonomous tractors move with efficiency across the farmland. Satellites can assess crop health from outer space, providing endless data in an effort to produce business intelligence once only accessible to Fortune 500 companies.

"Precision agriculture is on the brink of a new phase of development involving smart machines that can operate by themselves, which will allow production agriculture to become significantly more efficient. Precision agriculture is becoming robotic agriculture," said professor Simon Blackmore during a 2016 conference in Asia on the latest developments in robotic agriculture.

Blackmore is head of engineering at Harper Adams University, as well as head of the National Centre for Precision Farming in the UK.

It's Blackmore's university that recently showcased what may someday be possible. The project, dubbed Hands Free Hectare and led by researchers from Harper Adams and private industry, farmed one hectare (about 2.5 acres) of spring barley without a single person ever setting foot in the field.

The team repurposed, rewired, and mechanized farm equipment, ranging from a Japanese tractor to a 25-year-old combine. Drones served as scouts to survey the operation and collect samples to help the team monitor the progress of the barley. At the end of the season, the robot farmers harvested about 4.5 tons of barley worth £200k (about $262k).

"This project aimed to prove that there's no technological reason why a field can't be farmed without humans working the land directly now, and we've done that," said Martin Abell, mechatronics researcher for Precision Decisions, which partnered with Harper Adams, in a press release.

I, Robot Farmer

The Harper Adams experiment is the latest example of how machines are disrupting the agricultural industry. Around the same time that the Hands Free Hectare combine was harvesting barley, John Deere announced it would acquire a startup called **Blue River Technology** for a reported $305 million.

Blue River has developed a "see-and-spray" system that combines computer vision and AI to discriminate between crops and weeds. It hits the former with fertilizer and blasts the latter with herbicides with such precision that it can eliminate 90 percent of the chemicals used in conventional agriculture.

It's not just farmland that's getting a helping hand from robots. A California company called **Abundant Robotics**, spun out of the nonprofit research institute SRI International, is developing robots capable of picking apples with vacuum-like arms that suck the fruit straight off orchard trees.

"Traditional robots were designed to perform very specific tasks over and over again. But the robots that will be used in food and agricultural applications will have to be much more flexible than what we've seen in automotive manufacturing plants in order to deal with natural variation in food products or the outdoor environment."

Dan Harburg
Associate, venture capital firm Anterra Capital
AgFunder News

"This means ag-focused robotics startups have to design systems from the ground up, which can take time and money, and their robots have to be able to complete multiple tasks to avoid sitting on the shelf for a significant portion of the year," Harburg noted.

Eyes in the Sky

It will take more than an army of robotic tractors to grow a successful crop. The farm of the future will rely on drones, satellites, and other airborne instruments to provide data about its crops.

Companies like **Descartes Labs**, for instance, employ machine learning to analyze satellite imagery to forecast soy and corn yields. The Los Alamos, New Mexico startup collects five terabytes of data every day from multiple satellite constellations, including NASA and the European Space Agency. Combined with weather readings and other real-time inputs, Descartes Labs can predict cornfield yields with 99 percent accuracy. Its AI platform can even assess crop health from infrared readings.

The US agency DARPA recently granted Descartes Labs $1.5 million to monitor and analyze wheat yields in the Middle East and Africa. The idea is that accurate forecasts may help identify regions at risk of crop failure, which could lead to famine and political unrest. Another company called TellusLabs in Somerville, Massachusetts, **acquired by Indigo in 2018**, also employs machine learning algorithms and satellite imagery to predict corn and soy yields with similar accuracy.

Farmers don't have to reach orbit to get insights on their crops. A startup in Oakland, California, Ceres Imaging, produces high-resolution imagery from multispectral cameras flown across fields aboard small planes. The snapshots capture the landscape at different wavelengths, identifying insights into problems like water stress and providing chlorophyll and nitrogen level estimates. The geo-tagged images let farmers easily locate areas that need to be addressed.

Growing From the Inside

Even the best intelligence—whether from drones, satellites, or machine learning algorithms—will be challenged to predict the unpredictable issues posed by climate change. That's one reason more and more companies are betting the farm on what's called controlled environment agriculture. Today, that doesn't just mean fancy greenhouses, but everything from warehouse-sized, automated vertical farms to grow rooms run by robots—located not in the emptiness of Kansas or Nebraska but smack dab in the middle of urban America.

Proponents of these new concepts argue these high-tech indoor farms can produce much higher yields while drastically reducing water usage and synthetic inputs like fertilizer and herbicides.

San Francisco-based Iron Ox is developing one-acre urban greenhouses that will be operated by robots. These tech greenhouses are reportedly capable of producing the equivalent of 30 acres of farmland. Powered by AI, a team of three robots will run the entire operation of planting, nurturing, and harvesting crops.

Vertical farming startup Plenty, also based in San Francisco, uses AI to automate its operations and received a $200 million vote of confidence from the SoftBank Vision Fund in 2017. The company claims its system uses only 1 percent of the water consumed in conventional agriculture while producing 350 times as much produce.

"What I can envision is locating a larger scale indoor farm in the economically disadvantaged food desert, in order to stimulate a broader economic impact that could create jobs and generate income for that area," said Dr. Gary Stutte, an expert in space agriculture and controlled environment agriculture, in an interview with AgFunder News. "The indoor agriculture model is adaptable to becoming an engine for economic growth and food security in both rural and urban food deserts."

Still, the model is not without its own challenges and criticisms. Most of what these farms can produce falls into the "leafy greens" category and often comes with a premium price, which seems antithetical to the proposed mission of creating oases in the food deserts of cities. While water usage may be minimized, the electricity required to power these operations, especially the LEDs (which played a huge part in revolutionizing indoor agriculture), is not cheap.

Cultured Meats

Exponential technologies are not only revolutionizing how we grow vegetables and grains but also how we generate proteins and meat. The new cultured meat industry is rapidly expanding, led by startups such as Memphis Meats, Mosa Meats, JUST Meat, Inc., and Finless Foods, and backed by heavyweight investors including Bill Gates, Richard Branson, Cargill, and Tyson Foods.

Cultured meat is grown in bioreactors, using cells from an animal, a scaffold, and a culture. The process is humane and scientists potentially can make the meat healthier by adding vitamins, removing fat, or customizing it to an individual's diet and health concerns. Another benefit is that cultured meats, if grown at scale, would dramatically reduce environmental destruction, pollution, and climate change caused by the livestock and fishing industries. Similar to vertical farms, cultured meat is produced using technology and can be grown anywhere, on-demand, and in a decentralized way.

As is the case with robotic farming equipment, the cost of bioreactors is falling rapidly. In fact, the first cultured meat hamburger (created by Singularity University Faculty member Mark Post of Mosa Meats in 2013) cost $350,000. In 2018, Fast Company reported the cost had fallen to about $11 per burger, and Israeli startup Future Meat Technologies predicted it will produce beef at about $2 per pound in 2020, which will be competitive with existing prices. Prefer poultry? Check out research center New Harvest's progress in creating cultured chicken and turkey meat.

Two outstanding questions are whether cultured meat is safe to eat and how it will interact with the overall food supply chain. In the US, regulators like the Food and Drug Administration (FDA) and the US Department of Agriculture (USDA) are working out their roles in this process, with the FDA overseeing the cellular process and the USDA overseeing production and labeling.

NASA's Space Technology Expected to Improve Our Food

"The human eye has to be one of the cruelest tricks nature ever pulled," said Abi Ramanan in a talk called "The Future of the Food Chain," presented at Singularity University's Global Summit.

Ramanan explained that all the human eye sees is a tiny cone-shaped area of light in front of our faces, and it's restricted to a very narrow band of the electromagnetic spectrum. "We can't see around walls, we can't see electricity or radio signals, we can't see out of this bit," she said, indicating the corner of her eye. "We have wound up with the utterly mad and often fatal delusion that if we can't see something, it doesn't exist."

Ramanan is the CEO and co-founder of **ImpactVision**, a Singularity University **Portfolio Company** that's using **hyperspectral imaging technology to provide fast, non-invasive information** about foods and their quality attributes in the supply chain.

"You can think of it as a type of fingerprinting technology," she said. "It allows you to understand what the constituents of food products are, how much of them there are, and in fact, whether they should be there at all."

Ramanan pointed out that a third of the food produced worldwide gets thrown out, and modern agriculture is one of the biggest drivers of **climate change**.

In addition, she said, food fraud costs the global economy another $40 billion a year. Hyperspectral imaging is one promising solution to improve these dismal statistics.

The Old Ways

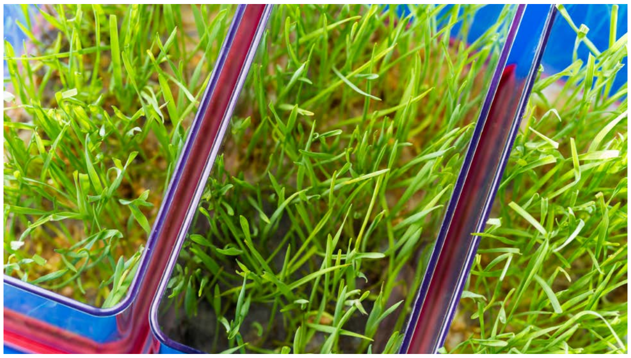
For food producers and retailers, current supply chain mechanisms are far outdated. "They're visual, destructive, and sample-based, or they're time-consuming lab tests," Ramanan said. "This is one of the causes of huge amounts of supply chain inefficiency, loss, and waste."

Some of the key measurements that happen in the food supply chain include:

- **pH**: A measure of freshness that's taken via a pH meter, a probe that's inserted into meat to get a reading. It would be too time-consuming to test every product using this method, so pH measurements are taken across only a small sample size of the total product.
- **Color:** Measured by visual comparison, usually by a supply chain operator, who holds up a color chart and compares it to cuts of meat. There's a wide margin for human error here.
- **Tenderness:** Assessed using an instrument that applies pressure to cut a piece of meat, and measures the pressure in newtons.

The New Way

Exponential technologies are now helping to reduce waste, human error, and time. A single hyperspectral image can provide information about pH, color, tenderness, lean fat analysis, and protein content. The technology combines digital imaging, or computer vision, with spectroscopy, the technique of acquiring chemical information from the light of a single pixel. A sensor



processes light and measures how it's reflected across hundreds of continuous wavelengths.

"What this means in practice is that you can take an image of a food product and understand the nutritional content, the freshness levels, and how much protein, fat, or moisture it contains," Ramanan said.

Hyperspectral imaging was **developed a few decades ago by NASA** for use in space. Until now, though, it hasn't had practical applications in other industries. Thanks to the "better, faster, cheaper" trend that's swept many of the technological components involved, that's changing. The size and cost of sensors has decreased, as has the cost of computation, while image processing power has increased.

ImpactVision's system analyzes hyperspectral images of food using chemometric models and machine learning. Its software then turns this data into actionable insights. Having more information about the pH of meat, the ripeness of fruits, or the freshness of fish can help food companies make real-time decisions earlier, which in turn reduces waste and fraud while maximizing yield and consistency.

Ramanan highlighted how the technology could address fraud issues in the fishing industry, such as frozen fish being defrosted and sold as fresh fish, or tilapia being sold as red snapper. "Fresh fillets reflect more light, so we can detect the difference," she said.

Another application of the technology is foreign object detection—things that aren't supposed to be in our food, but somehow find their way there: plastic, paper clips, metals, etc. The software is able to group pixels with similar spectral profiles together to detect foreign objects within, for example, a batch of sugar.

Most traditional machine vision systems need to be fed hundreds or thousands of images in order to "learn" to classify things. Hyperspectral images are different in that they contain two data sets: spatial and spectral.

Each image is divided into about 25,000 pixels, with each pixel containing 224 spectral values. One image occupies 700 megabytes, which contains a lot of information. This means the system can be trained to group pixels with similar profiles together utilizing fewer images than a traditional system.

Balance of Power

"The core of what this allows is a shift from subjective supply chain measurements to much more objective data," Ramanan said.

Retailers have a lot of power in the modern supply chain, while the more vulnerable players—like farmers and other food producers—don't have a way to provide objective measurements to guarantee the quality of their food. Developing close product specifications that can be measured both objectively and accurately will help change this—in conjunction with the equally important goal of reducing waste.

For example, ImpactVision is currently working with a company that sources 30 to 40 million avocados a year, a quarter of which are wasted due to being under- or overripe. The company is developing a model that can classify ripeness non-invasively, ripen avocados in select bands, and then ship out to the restaurant level more in line with their specifications.

Ramanan cautioned that the food system and supply chain are highly complex, and there's no individual technology that can solve all the issues they face. "There will need to be consumer-led awareness campaigns," she said. "Supermarkets need to relax their superficial cosmetic standards. We as consumers also need to change our preferences, and change our attitudes."

Vertical Farming in Action

The Eindhoven High Tech Campus, a 90-minute train ride south from Amsterdam, consists of two rows of nondescript mid-rise office buildings on either side of a wide, tree-lined road. In typical Dutch fashion, there's more parking for bikes than cars, and the campus is flanked by stretches of neatly-maintained green fields and canals.

The place doesn't have an especially high-tech feel to it. But, on the third floor of a building near the end of the road, a division of Philips Lighting called **GrowWise** is using technology to tackle a crucial question: what are we going to eat once there are over nine billion people on Earth?

GrowWise is a vertical farming research facility, and in conjunction with Dutch fresh food distributor **Staay Food Group**, it's laying the groundwork for **the first commercial vertical farm in Europe**, slated to open near Amsterdam in 2019.

No Sun + No Soil = Organic Plants?

Since humans began farming, sunlight and soil have been fundamental ingredients. If you take away these two basic inputs, how do plants grow?

Gus van der Feltz, Global Director of City Farming, is happy to discuss the ins and outs of vertical farms and the opportunities and challenges the field will face in coming years. "You can think of a vertical farm as a black box," van der Feltz said. "We look at it as an integrated system, trying to create vegetables in a closed environment." Solar light, van der Feltz explained, is spread across a spectrum ranging from UV to infrared. In photosynthesis, red and blue wavelengths of light interact with chlorophyll to help form glucose and cellulose, the structural material in cell walls. LEDs can reproduce this effect faster even than the sun. Time from seed to harvest at GrowWise is 30-40 days, as compared to 60-65 days in a typical greenhouse, according to van der Feltz. "What we've done with LEDs is optimize the conditions for growth. There are elements of sunlight that plants don't use as efficiently, and those can be reduced or taken out," van der Feltz said.

The crops need different intensities of light as they pass through stages of growth, and they're constantly monitored by sensors and software that tweak their conditions as necessary. Van der Feltz explained that triggering the right combination of processes in photosynthesis, in combination with other growth factors, can also create desired effects. "With the right lighting conditions, we can make lettuce turn purple or red. We can make strawberries sweeter," he said.

Each plant sat in a thimble-sized container of sterilized coconut bark, which served as a substrate for germination and root development. From there, the roots extended into shallow troughs of nutrient-rich water—the plants, in hydroponic farming fashion, were constantly in water, rather than being periodically sprayed or on a timed drip.

Food and the Future

The Dronten facility will be 900 square meters (9,680 square feet), with a total cultivation area of 3,000 square meters (32,290 square feet). Though this pales in comparison to 2019's biggest vertical farm in the world—AeroFarms' 70,000-square-foot facility in Newark, New Jersey—it will be the largest in Europe. Outside Europe and the US, vertical farms also exist in Japan, Korea, Singapore, and Canada, and a facility much larger than Aerofarms is planned in Shanghai.

It's no coincidence that most of these farms are near big, densely-populated cities. The UN's 2014 World Urbanization Prospects report predicts population growth and urbanization will add 2.5 billion people to the world's big cities by 2050. That's a whole lot of people who will be buying all their food rather than producing any of it. Agricultural yields, then, will have to increase significantly, and since much of the world's arable land is already being farmed, we'll need to get a bit more resourceful with our food supply.

Perhaps not surprisingly, vertical farms eventually will get their energy from solar panels. This will provide an organic growing method that requires no fertilizer or pesticides, produces no runoff or pollution, uses a fraction of the water and soil of traditional farms, and yields consistent harvests year-round, even in extreme or unusual weather.

"You can create optimal growing conditions for the crop and you don't need to wash it," van der Feltz said. "The washing process damages the leaves and causes them to decay faster. Having the growth facility nearby decreases travel time and means the food will be fresher."

The Consumer Is Still King

As rosy as this all sounds, it doesn't mean people will embrace vertically farmed food with open arms. Food is a sensitive topic many consumers take very seriously. If we are what we eat, people may not love the idea of eating food that, for all its merits, is grown under decidedly artificial conditions.

Van der Feltz recognized widespread adoption of vertically-farmed food may be a challenge. "We understand some people may feel uneasy about food grown with no sunlight," he said. Consumer education will play a key role in getting people comfortable with purchasing and eating LED-grown greens.

At the same time though, food preferences are shifting, and for the better, as far as vertical farming is concerned. "In the Western world there's a growing demand for convenience products that have already been washed and are ready to use," van der Feltz explained. His confidence in GrowWise products, for one, is unwavering. "We test our produce regularly for pathogens and nutritional quality, and each time the results are excellent," he said. "They serve this lettuce here in our cafeteria. I take it home to my family. My kids love it."

Gene Editing Could Help Feed 9.7 Billion People

While it's no secret that we will be challenged to feed the rapidly expanding global population, new **genome editing technologies could hold the answer**, according to scientists.

The number of humans on this planet is expected to hit 9.7 billion by 2050, **and crop demand is predicted to increase by 100 to 110 percent** of 2005 levels over the same period. At the same time, the Intergovernmental Panel on Climate Change predicts that changing weather patterns will **almost certainly have a negative impact on crop yields**.

Traditional plant breeding approaches have managed to achieve impressive increases in crop yield in the past, but the process is laborious and can take decades to develop improved varieties. More recent genetically modified (GM) crops have resulted in further improvements by transplanting genes from one organism to another.

Now, the emergence of the gene-editing tool CRISPR/Cas9 is making it possible to precisely edit the native DNA of organisms with the potential to dramatically increase crop yields. In **a recent commentary in the journal *Science***, Armin Scheben and David Edwards, from the University of Western Australia, say we should embrace the opportunity.

Unlike previous approaches to GM crops that introduce foreign DNA into an organism, genome editing achieves much the same outcome as selective breeding—but in a much faster and more selective way, and without having to rely on natural genetic variation.

CRISPR/Cas9 effectively acts like a find-and-replace tool in a word processor, allowing researchers to target very specific sections of DNA and delete or substitute them. Aside from allaying some people's **fears about 'Frankenstein food,'** the approach is also cheaper, easier, and more precise than earlier approaches.

Importantly, it allows scientists to edit multiple targets simultaneously, enabling what is known as "trait stacking" and manipulation of complex gene networks related to things like drought tolerance.

"Many simple trait improvements involving few genes have likely already been made in staple crops, so that trait stacking and more complex modification of gene networks is required to further enhance global yields," the researchers wrote.

The commentary highlights several promising lab demonstrations of how genome editing can be used to enhance pest resistance and drought tolerance in crop plants. There have even been field tests of tomato plants modified to flower and crop early, which demonstrates the possibility of shifting harvest times to match changing climate patterns.

Further down the line, genome editing may even make it possible to precisely engineer more complex traits, such as photosynthesis efficiency. **A 2015 study in *Cell*** showed that supercomputers are making it possible to model the entire photosynthetic pathway and identify bottlenecks that could be targeted by genetic engineering.

But, it could be a long time for these innovations to translate into yield boosts.

> *"Anything we discover in the lab now won't be in a farmer's field for 20 to 30 years."*
>
> **Lead author Stephen Long, plant biologist, University of Illinois at Urbana-Champaign (UIUC)**
> **SciDev**

Part of the problem is that, while we can now easily target genetic changes, we don't actually understand the genomes of most crops well enough to know what parts to target.

"Despite the wealth of genomic data available for major crops, researchers have yet to broadly connect genotype with the phenotype information, model the behavior of gene networks, characterize regulatory elements, and develop databases to integrate and analyze this information," Scheben and Edwards wrote.

This means more basic research into plant biology will be needed before the full promise of genome editing can be realized. Even then, the technology may run into other obstacles, including fears around GM crops and associated regulation.

The technology is so new that few countries have clear policies to deal with genome-edited crops. Whether regulations lump genome-edited crops in with GM crops, classifying them the same as selectively bred varieties, or give them their own designation is likely to have a major impact on their adoption.

A 2016 editorial in *Nature* called for regulators to look at the product rather than the technology, pointing out that the approach achieves the same outcomes as selective breeding, just much faster. Key to that will be making a clear distinction between GM crops and genome-edited ones, particularly in the public sphere. "Transparency and accuracy on the part of scientists and researchers will help to dispel negative or stigmatizing perceptions of genome-edited crops and hopefully pave the way for sensible policies for their regulation and use."

Drones Find a Home on the Farm

Beyond the genetic origins of agricultural products, crop monitoring is another aspect of the production process that's ripe for optimization. Drones are in use across various industries, and there are many effective applications in agriculture. Agricultural drones are becoming an integral tool for farmers and food producers, and likely helped get at least one of your meals on the table today.

With the global population continuing to grow, efficient food production is critical to maintaining human health and quality of life worldwide. Drones in agriculture have already enabled major advances in efficiency, and more are surely on the way.

Modern Farms Are Big... Really Big

Imagine a farm four miles wide by 40 miles long: 160 square miles of crops that need to be planted, irrigated, fertilized, monitored, and harvested. Of all these tasks, monitoring could be considered the most important: if a section of crops is battling pest infestation or poor irrigation, the issue needs to be identified and addressed before it spreads.

The old-fashioned crop monitoring method was simple: walk through the fields and look at the plants. But for 160 square miles (not to mention much larger areas), this would take a while.

Until recently, satellite imaging was the most cutting-edge solution, allowing farmers to view aerial photographs of large swaths of land, but a lack of precision, low image quality on cloudy days, and high costs pointed to a need for cheaper, better imaging and monitoring techniques.

Send in the Drones

Drones give farmers a new, low-altitude perspective. Their flight altitude ranges from a few meters up to 120 meters above the ground, the maximum imposed on unmanned aircraft operating without clearance from the Federal Aviation Administration.

Within this altitude range, drone cameras can take multispectral images, using visible light (VIS) and near-infrared (NIR) light to identify which plants reflect different amounts of green light and NIR light. Together, these are used to produce multi-spectral images that can highlight healthy and distressed plants. Multiple images of the same area over time can be combined to create a time-series animation, which shows large-scale changes in crops and opportunities for better crop management.

Beyond higher resolution, multispectral images, and on-demand availability, crop monitoring via drones is cheaper than other methods. As technology advances, prices will continue to drop. In fact, the price of a basic agricultural drone is already relatively affordable at $1,000.

Besides the up-front cost, regulation is another potential barrier to entry for farmers interested in using drones. Passed in 2012, Section 333 of the FAA Modernization and Reform Act gave the US Secretary of Transportation the authority to determine whether an airworthiness certificate is required for an unmanned aircraft system (UAS) to operate safely in the national airspace. As of August 2015, the FAA had issued more than 1,000 Section 333 exemptions, and regulations have loosened even more since then; regulators are recognizing the importance of enabling drone technology across multiple industries. Besides crop monitoring, drones can help with:

- **Irrigation**: Hyperspectral, multispectral, or thermal sensors pinpoint dry areas, and once a crop is growing, they facilitate the calculation of the vegetation index and show the heat signature.
- **Spraying:** Distance-measuring equipment enables a drone to adjust altitude as the topography and geography vary, scanning the ground and spraying only the necessary amount of pesticide for even coverage, reducing the number of chemicals that leach into groundwater.
- **Planting:** UK startup BioCarbon Engineering has developed a technique where drones carry pressurized canisters of biodegradable seed pods and shoot them into the ground, where the pods break open and seeds can take root.

A drone report released in March 2013 by the Association for Unmanned Vehicle Systems International predicted that the legalization of commercial drones would create more than $80 billion of positive economic impact between 2015 and 2025. The predicted biggest sector of that growth? Agriculture.

Food for Thought

Although we're developing tools and technology that show remarkable progress in ending food insecurity, there is much work to be done. For the first time ever, the goal of enabling the consumption of sustainable, and nutritious food for people around the world could be within our reach.

An oft-quoted statistic from the Food and Agriculture Organization of the United Nations is that the world must boost food production **by 70 percent** to meet the needs of the growing population.

To reach this ambitious goal, we must organize and move decisively. There is no time to lose in sharing the technological breakthroughs, as well as developing the policies and regulatory environment, that can help us accelerate progress toward ending global hunger and malnutrition.

Agricultural technologies are being integrated into the larger collaborative economy—connected by digital platforms, the cloud, and the Internet of Things—and powered by AI. Technology will help us use resources more effectively, and connect people to a new ecosystem of food, water, and energy. It will also aid in the development of a circular economy that is designed to be restorative and regenerative, minimizing waste and maximizing recycling and reuse to build economic and social capital.

Though formidable challenges remain, exponential technologies have given us the start, and it's up to us to execute on their potential to create global programs to reduce hunger and malnutrition quickly and sustainably.

At **Singularity University**, we're laying the groundwork for exponential change. With our learning and innovation platform, proven tools and methods, and world-class Faculty, Singularity University helps organizations navigate the changing business climate and competitive landscape and seize opportunities presented by accelerating and converging exponential technologies like AI, robotics, nanotech, and more. We also help transform organizations of all sizes to help them get out in front of market disruptions and achieve exceptional business results.

To learn more about how Singularity University can help your company and leadership team be exponential, explore our suite of powerful enterprise solutions at su.org/enterprise designed to uplevel your leadership, innovation, and strategy; help you monitor emerging threats and opportunities; and empower you to measure the effectiveness of innovation at your organization.

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