The reinvention of agriculture

Many people still have an outdated notion of what farming entails and are unaware how much it involves high technology. Even traditional tools like giant combines, sprayers and tractors are equipped with GPS receivers and seeders, and fertilizer systems use satellite guidance.

Farming is on the cusp of an even greater technological leap which will once again increase the productivity of US farmers and allow them to grow more food more economically. This has been the history of farming. Only through the application of science and technology has farming been able to increase crop yields. According to the US Department of Agriculture (USDA), farm production nearly tripled between 1948 and 2017 even as land and labor use declined. Without the application of science and technology, US farmers would not have been able to feed the growing US population and become major exporters of crops to the rest of the world. The US is the largest producer and exporter of corn, the second largest producer and exporter of soybeans and the fourth largest producer of wheat and the third largest exporter of wheat. It is the largest exporter of agricultural products.

Wanted: More land — or more productive farms

The application of new scientific advances and technology is essential to feed a growing world population at a time when land under cultivation worldwide may decline because of urbanization, desertification, the declining number of farmers, and climate change. According to the USDA, there were 2.04 million farms and ranches in the U.S. in 2017, down more than 3% from 2012. Land devoted to agriculture fell by around 2% to 900.2 million acres from 914.5 million acres in 2012. The average age of farmers was 57.5 years which was 1.2 years above the level in 2012.

A 2015 study conducted by The University of Sheffield’s Grantham Centre for Sustainable Futures concluded that the world has lost about of one-third of its arable land as a result of erosion and pollution over the last forty years. The loss far outstrips the pace of natural processes that replace diminished soil. The report called the loss “catastrophic” and said the trend was close to being “irretrievable.”

It is essential that agriculture becomes more productive to feed a growing world population that is forecasted to rise from 7.9 billion in 2022 to 9.9 billion in 2050. This can only be accomplished by the further application of science and technology, and not as some suggest by going backwards in time to a much simpler and idealized form of farming that shuns the use of biotechnology and technological advances such as artificial intelligence (AI), drones, robots and microchips which will be implanted in animals to track them from birth through processing and monitor their health.

Artificial intelligence

AI will completely revolutionize farming. It will be used to detect plant diseases, pests and weeds and decide which and how much herbicides, insecticides and fungicides to use. It will give farmers precise dates to sow seeds in order to maintain maximum yields, give insights into soil health, provide recommendations on the application of fertilizers, provide weather forecasts and determine water usage from irrigation.

According to a Food and Agriculture Organization Report, Agriculture is slowly becoming digital and AI in agriculture is emerging in three categories, (i) agricultural robots, (ii) soil and crop monitoring, and (iii) predictive analytics. Farmers are increasingly, using sensors and soil sampling to gather data and this data is stored on farm management systems that allows for better processing and analysis.

Robotics

Farms of the future will rely more on robots. In conjunction with AI, robots will pick fruits and vegetables, sow seeds and help to pack fruits and vegetables into boxes for shipment. A New York Times article on agricultural robots reported on a robot named TerraSentia, developed by an engineer at the University of Illinois at Urbana-Champaign, that resembles “a souped-up version of a lawn mower, with all-terrain wheels and a high-resolution camera on each side” that sees surroundings and “navigates a field by sending out thousands of laser pulses to scan its environment. A few clicks on a tablet were all that were needed to orient the robot.” The robot had the ability to measure the height of every plant it examined. It is

> designed to generate the most detailed portrait possible of a field, from the size and health of the plants, to the number and quality of ears each corn plant will produce by the end of the season, so that agronomists can breed even better crops in the future. In addition to plant height, TerraSentia can measure stem diameter, leaf-area index and… the number of live grain- or fruit-producing plants — or all of those traits at once.

Robotics have been devised to pick many kinds fruits and vegetables including apples, kiwis, peppers, strawberries, tomatoes, oranges, grapes and lettuce. An AI flying drone has been invented to spot ripe fruit and pick it autonomously. The drone can work 24 hours a day.

Flying autonomous robots can work 24 hours a day, and only pick ripe fruit.
Image: Kubota/Tevel

Drones will not only be used to pick fruit but will also be utilized to disperse herbicides, insecticides, fertilizers, fungicides and seeds and gather crop data.

Nano-tech

Nanotechnology will also be utilized extensively in farming. An article entitled, "Nanotechnology in Sustainable Agriculture: Recent Developments, Challenges, and Perspectives", noted,

> Nanotechnology monitors a leading agricultural controlling process, especially by its miniature dimension… The ambition of nanomaterials in agriculture is to reduce the amount of spread chemicals, minimize nutrient losses in fertilization and increased yield through pest and nutrient management. Nanotechnology has the prospective to improve the agriculture and food industry with novel nanotools for the controlling of rapid disease diagnostic, enhancing the capacity of plants to absorb nutrients among others. The significant interests of using nanotechnology in agriculture includes specific applications like nanofertilizers and nanopesticides to trail products and nutrients levels to increase the productivity without decontamination of soils, waters, and protection against several insect pest and microbial diseases. Nanotechnology may act as sensors for monitoring soil quality of agricultural field and thus it maintains the health of agricultural plants.

Nano-sensors might be able to be implanted in crops to monitor their health in "real" time thus alerting farmers to stress conditions and possible crop losses. Canadian scientist

Gopinadhan Paliyath is researching nanomaterials that can be sprayed on fruits and vegetables after being harvested to slow down the ripening process. This will help to reduce spoilage and waste.

Just as auto companies are working to develop driverless and autonomous cars and trucks, companies that manufacture combines and tractors are also working on self-driving vehicles. John Deere has developed hardware and software that combines with machine learning and GPS powered auto steer feature to manufacture a fully autonomous tractor. According to John Deere, “With this technology, farmers will not only be able to take their hands off the wheel of their tractor or leave the cab – they’ll be able to leave the field altogether, letting the equipment do the work without them while monitoring things remotely using their smartphones.” Production is expected to begin in the fall of 2022.

Who needs dirt?

Farming is likely to take other forms than planting seeds in soil. For example, hydroponics is growing in importance. It is a way of growing crops in nutrient-rich water. Although most crops can be grown hydroponically, the most common crops grown are leaf lettuce, tomatoes, peppers, cucumbers, strawberries, watercress, celery and some herbs.

A report on the Hydroponics Market by Markets and Markets indicated;

> The hydroponics market was valued at $9.5 billion in 2020 and is expected to reach $17.9 billion by 2026… plants grown in hydroponic systems have achieved 20%–25% higher yield than the traditional agriculture system, with its productivity being 2–5 times higher… With more and more varieties of fruits taken under cultivation in the hydroponics market is estimated to grow faster… Europe has traditionally been at the forefront of implementing advanced techniques in hydroponic smart greenhouse horticulture.

Getting vertical

Vertical farming is a relatively new farming method that is attracting increased interest. According to Bowery Farming, one of the major vertical farming companies, it is an

> agricultural process in which crops are grown on top of each other, rather than in traditional, horizontal rows. Growing vertically allows for conservation in space, resulting in a higher crop yield per square foot of land used. Vertical farms are able to dramatically increase productivity per acre by accommodating many more crops to grow upward, all while occupying the same amount of land.

Vertical farms do not use soil. Instead, crops are grown hydroponically, aeroponically (using air or mist) and aquaponically, which combines aquaculture (rising aquatic animals such as fish or shrimp in a tank) and hydroponics with the nutrient rich aquaculture water fed to hydroponically grown crops. Indoor vertical farms supply their own light source for year-round photosynthesis through energy-efficient LED lights. One of the major advantages of vertical farming is that it saves on water use with Bowery farming noting that it gives crops grown in an indoor environment

> a precise amount of purified, nutrient-rich water to thrive. Water is continuously recirculated in our irrigation system, resulting in significant water savings compared to field-grown crops.

On January 25, Vertical farming received a big vote of confidence when Walmart announced it will invest in the vertical farming company Plenty, based in California. Later this year Walmart stores in California will begin to carry leafy greens such as lettuce varieties (including kale, arugula and spring mix) produced by Plenty. All of the company's farms are located in California but there are plans to produce crops in the East Coast and to expand the line of produce to include strawberries and tomatoes in 2023.

Plenty San Francisco. Credit: Spencer Lowell/Plenty/Courtesy of Walmart via AP

Greenhouses have long been used to grow crops, but increasingly they are utilizing high-technology to increase productivity in a manner that is eco-friendly and economically efficient. In the Netherlands, the second largest agricultural exporter after the US, greenhouses are used extensively to produce agricultural products. They are increasingly incorporating high technology in their production process.

According to Dr. Leo Marcelis, head of Horticulture and Product Physiology at the Wageningen University and Research,

> In greenhouses, the excess water and nutrients are collected and re-used. This prevents leakage of water and nutrients to the ground or surface water. In outdoor soil-based cultivation much more water and nutrients are needed and nutrients like nitrogen and phosphorous are leaking, polluting ground and surface water. Moreover, in this leaked water, there might be

chemicals like crop protection agents.

Jonathan Webb, founder and CEO of AppHarvest, a high-tech greenhouse company in Kentucky, expects to grow about 40 million pounds of produce a year in a 60-acre greenhouse facility, which is roughly the production of a 1,500-1,800-acre open field farm in California.

The “G” words (genetic engineering)

Genetic engineering of plants and animals will be a very important part of the future of agriculture. Genetic engineered seeds that are disease, drought, insect, bruising and browning resistant will be cultivated as well as crops that a nutritionally fortified with Vitamins, minerals and antioxidants. Plants will be genetically engineered to manufacture their own nitrogen thus reducing the need for fertilizers. Biopesticides will be used to control insects and pests. Gene-editing will also be of value to help with insect control. Scientists at the University of California, San Diego, for example have developed a method utilizing CRISPR technology to replace an insecticide-resistant gene in fruit flies with the normal insecticide-susceptible form. This could potentially significantly reduce the amount of insecticides used.

Research and development of genetically engineered animals have been stifled by the heavy hand of regulation and as a result only two genetically animals have been approved for commercialization. The first is a GMO Salmon which had an arduous journey until it was finally approved for sale, because of vigorous opposition from Anti-GMO proponents. The second is a pig that is genetically engineered to eliminate alpha-gal sugar which can cause an allergic reaction in some people. The pig may also be used to produce biomedical products for humans such as tissue and blood thinning products.

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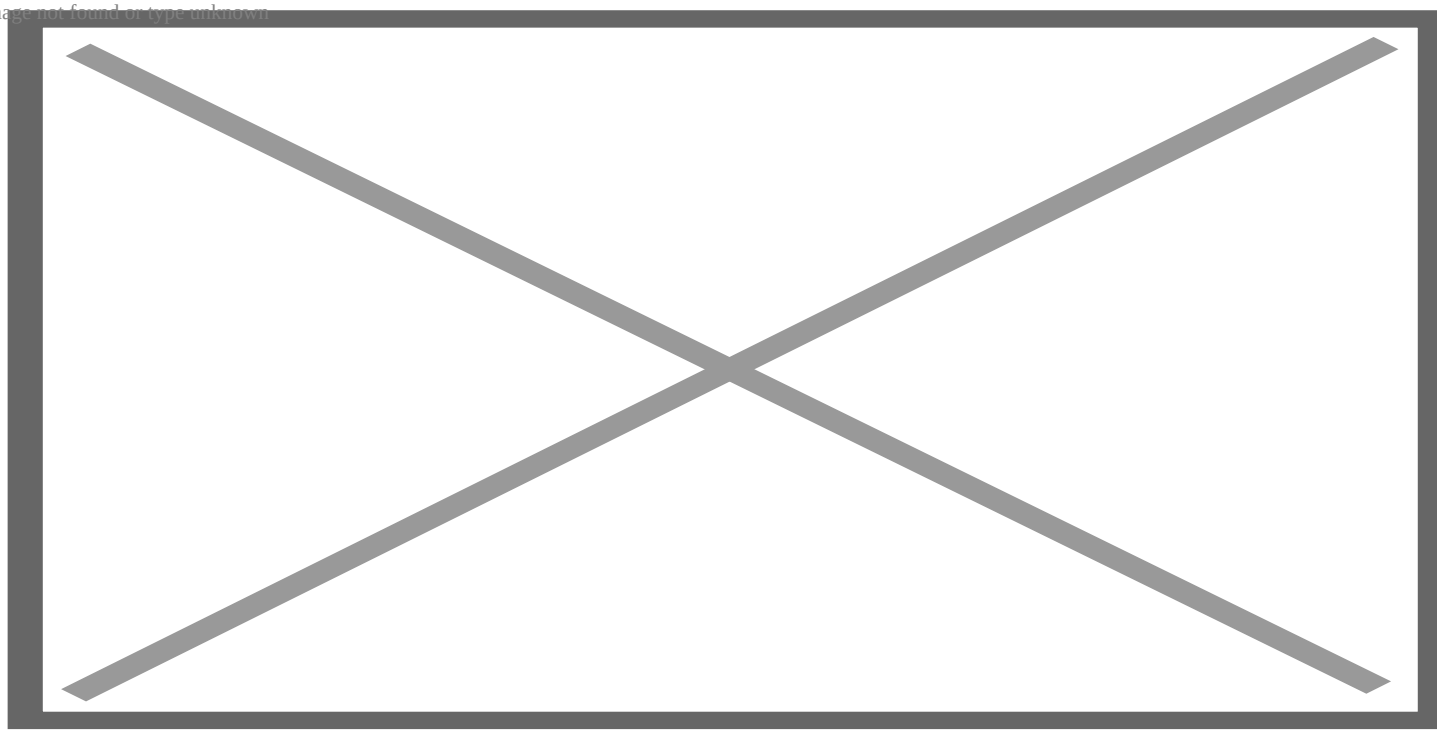

Credit: Maritime Injury Law

If and when there is less regulation of GE animals, there will be plethora of such animals that will be of great value to farming. Among them:

- GE heat resistant cows that will help them deal with global warming and a more muscular pig that will provide more meat.
- GE goats that produce spider silk in their milk that can be used for making artificial ligaments and tendons, eye sutures, and for jaw repair. The silk could also be used to make bulletproof vests and improved car airbags.
- Goats have also been genetically engineered to produce high levels of a human antimicrobial protein in their milk that has proved effective in treating diarrhea in young pigs and could be used for the benefit of humans.
- A three-year study of GMO sheep in Australia concluded that they grow bigger and faster, produce double the amount of milk and can grow more wool but require more care because excess growth hormone causes their hooves to overgrow and so require regular clipping.
- A cow has been genetically modified to make low allergy milk. Researchers at the University of Edinburgh's Roslin Institute have genetically modified chickens to produce human proteins in their eggs that may be used to make drugs.
- A chicken has been genetically modified so that it does not transmit birdflu. Pigs can be genetically modified to resistant diseases.

Nicola Patron of the Earlham Institute of the UK, has highlighted the importance of using gene-editing technologies, saying,

> We've been changing plant genomes for thousands of years… Since the 1980s, we've had the ability to use recombinant DNA technologies to insert DNA sequences into plant genomes in order to confer useful traits, such as resistance to insect pests. This could be a DNA sequence from a different individual of the same species, from a closely related species, or from a more distantly related species. Such crops became known as genetically modified organisms (GMOs)…

An article in the Guardian newspaper noted,

> Smooth or hairy, pungent or tasteless, deep-hued or bright: new versions of old fruits could be hitting the produce aisles as plant experts embrace cutting-edge technology… While researchers have previously produced plants with specific traits through traditional breeding techniques, experts say new technologies such as the gene-edited tool Crispr-Cas9 could be used to bring about changes far more rapidly and efficiently. It could, they say, potentially open the door to a new range of fruits and vegetables that look, taste and feel very different to those we are used to.

Gene-editing may be essential to deal with the impact of climate change by creating drought tolerant crops. This is especially important as climate change poses a great threat to food security in many regions of the world. According to the Intergovernmental Panel on Climate Change, crop yields decline 5 percent for every degree of temperature rise. A warmer world climate is likely to see less rainfall in many parts of the world.

Pairwise, an Agri-biotechnology company located in North Carolina, is in the forefront of utilizing gene-editing to make food more appealing to consumers. For example, it is working on improving the nutritional content of lettuce. CEO Tom Adams noted that

> most people eat lettuces like iceberg and romaine because of their taste. However, they have much lower nutritional value than greens like kale and arugula. We found a relative of kale that actually has characteristics a lot like the lettuces… but has a nutrient value of the kales and arugulas… Unfortunately, it doesn't taste very good. It tastes sort of like horseradish.

Using CRISPR, Pairwise has been able to eliminate the biochemical pathway that creates that horseradish taste, so it essentially tastes like lettuce but has the nutrient qualities of kale.

Pairwise is also working to alter the DNA of blackberries and black raspberries to make them tastier, remove the seeds and remove thorns from the bushes to make harvesting more efficient and safer. It is also working on developing a pit-less cherry. If it is successful with regard to the cherry, it will try to de-pit other fruits such as nectarines.

Benson Hill, located in Missouri, is using gene-editing technology to try to enhance protein content and flavor that have been lost in soybeans through successive generations of breeding for yield. A similar approach is being used for yellow peas. It is also working with tomatoes to enhance favor. Jason Hill, the company's Chief Technology Officer, said,

> these kinds of food crop improvements could be coming very rapidly. You start stacking these technologies in your toolbox, and it really changes the face of plant development from what it has been for the last 20 or 30 years.

TreeCo is working with gene-editing to improving commercially important trees such as poplar, eucalyptus, pine and hemlocks by making them pest resistant and drought tolerant. Rodolphe Barrangous, the company's co-founder, said,

> there was a great difference between using traditional tree breeding techniques and CRISPR as tree breeding though traditional methods is slow and challenging as each generation of trees require many years to mature. With CRISPR though, it was possible to edit tree cells and then grow them in a greenhouse. The time needed for tree breeding can decrease by as much as 10-fold.

Professor Harry Klee of Florida University's horticultural sciences department is researching the chemical and genetic make-up of fruit and vegetable flavors. He is particularly focused on the tomato with the goal of identifying the genes that control flavor. If he can do that, he could ultimately manipulate those genes in a manner to enhance the flavor of a tomato. Scientists meanwhile are studying the genetic composition of citrus fruits to see if there may be a way to diminish or eliminate the bitterness attributed to the major bitter compounds naringin and limonin.

Browning and bruising of fruits and vegetables are a major problem as they lead to billions of dollars in losses as a result of spoilage. An article entitled, "Can gene editing reduce postharvest waste and loss of fruit, vegetables, and ornamentals?", noted,

> Postharvest waste and loss of horticultural crops exacerbates the agricultural problems facing humankind… Fruits and vegetables provide us with a vast spectrum of healthful nutrients… These commodities are, however, highly perishable. Approximately 33% of the produce that is harvested is never consumed since these products naturally have a short shelf-life, which leads to postharvest loss and waste. This loss, however, could be reduced by breeding new crops that retain desirable traits and accrue less damage over the course of long supply chains.

Non-browning and non-bruising potatoes and apples have been created and are being sold commercially in the US. The non-browning potato, which has been sold in the US since 2015, was developed by J.R. Simplot. It was created by a method of gene silencing called RNA interference (RNAi). This results in a potato that hides the symptoms of blackspot bruising. Non browning apples are created by using a similar technology with RNAi utilized to diminish polyphenol oxidase (PPO) enzymes**,** which are responsible for causing browning. Plant pathologist Yinong Yang of Penn State University used CRISPR-to develop a button mushroom that resists browning. It however has not been commercialized.

Credit: Food Safety News

Chinese scientists have used gene-editing to develop salt tolerant rice. Salinity is a major threat to crops which cannot grow with high levels of salt. Over 400 million hectares of land throughout the world is affected by high levels of salt content. Climate change, rising sea levels and tsunamis are increasing the total every year. High levels of salt is especially harmful to rice production and thus salt tolerant varieties would result in higher yields for a crop that is the third largest in the world after wheat and corn.

Scientists have also been able to genetically-engineer rice so it emits less methane.

This is particularly important as rice is responsible for between 7% and 17% of human induced methane emission. The methane is caused when sugars produced by photosynthesis leak into the soil via the roots, where they are used by methane producing soil microorganisms. The gene-edited rice however stores more sugar in the grains and stems. In a three-year trial, methane reductions were especially pronounced in the summer when hot temperatures stimulate higher sugar production.

It may be possible to utilize gene-editing as a method of altering the ripening period of fruits or vegetables. A December 2016 news release from the Cold Spring Harbor Laboratory noted,

> Using a simple and powerful genetic method to tweak genes native to two popular varieties of tomato plants, a team at Cold Spring Harbor Laboratory (CSHL) has devised a rapid method to make them flower and produce ripe fruit more than 2 weeks faster than commercial breeders are currently able to do. This means more plantings per growing season and thus higher yield. In this case, it also means that the plant can be grown in latitudes more northerly than currently possible—an important attribute as the earth's climate warms. Our work is a compelling demonstration of the power of gene editing.

Associate Professor Zachary Lippman, who led the research said,

> Applications can go far beyond the tomato family to include many major food crops like maize, soybean, and wheat that so much of the world depends upon… it is about more than simply increasing yields. It's really about creating a genetic toolkit that enables growers and breeders in a single generation to tweak the timing of flower production and thus yield, to help adapt our best varieties to grow in parts of the world where they don't currently thrive.

In October, 2021, Argentina became the first country to approve the commercialization of genetic engineered wheat. It was modified to be drought resistant and was developed by the Argentine biotechnology company Bioceres in collaboration with the National University and the National Commission for Science and Technology. In November, 2021, Brazil approved the sale of flour produced from the drought tolerant wheat. The approval however does not apply to wheat itself but only to the flour.

Scientists have found a way to genetically engineer castor beans to eliminate ricin, a toxic compound. By doing so, the bean can be used as a source of proteins for animals.

The J.R. Simplot Company and Plant Sciences Inc. have announced plans to produce a more durable strawberry via gene-editing. This is especially important as more than a third of all fresh strawberries are

thrown away because they’re bruised, moldy or mushy. The goal is to grow strawberries that have a longer shelf life, longer growing season and reduced spoilage.

Credit: Glenn Lowson

Japanese scientists have been able to utilize Crispr to alter the color of a morning glory from violent to white by disrupting a single gene. Genetic engineering could be used to not only change the color of flowers but to enhance their scent, remove pollen and possibly make them glow in the dark.

Scientists are working on creating genetically engineered plants that will be able to make their own nitrogen supply. This is important as producing nitrogen fertilizers is a very energy and fossil fuel intensive process. In addition, the use of nitrogen as a fertilizer has led to pollution of rivers and oceans which causes algae blooms that suffocate marine life and are very costly to clean up.

The new forms of genetic engineering, will prove to be a versatile tool to make food crops tastier, more nutritious, drought and insect resistant and with a longer storage life. It will also help in the fight against climate change. It is a technology with a great deal of promise and potential and we are only at the early stages of research and development.

Agriculture is going to undergo a profound revolution as it becomes more high-tech and incorporates more aspects of genetic engineering. This is a necessity in order to increase productivity at a time of growing world population and the possible continued shrinkage of land area relegated to farming due to climate change, desertification and urbanization. There are those who falsely believe the solutions lies in looking backwards and adopting simpler, quaint and archaic ways of the past that abstain from using biotechnology, AI and robots. But that will condemn the world to an inadequate food supply at a time when the world population is headed towards 10 billion. Only the continued application of science and technology to farming can ensure an adequate food supply at reasonable prices.

Steven E. Cerier is an international economist and a frequent contributor to the Genetic Literacy Project.