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Farming in extreme environments: technology ploughs ahead

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Farming in extreme environments is getting harder. As our population increases and climate change keeps pushing on, agricultural technologies are trying to keep up, even more so in places where life is difficult at the best of times.

The global population is expected to rise from seven billion now to nine billion in 2050, so space for cultivating food is becoming harder to find, especially in urban areas, where people can be practically stacked on top of each other. Urban agriculture can help tackle this problem and has increasingly become a popular form of farming in recent years.

As well as significant health and wellbeing benefits to the people it caters for, urban farming optimises use of space lost to housing and industry. It also decreases the use of vital resources like water.

This kind of farming can take on many forms, such as rooftop gardens or greenhouses, indoor and vertical farms, and hydroponic growing systems.

Vertical farming, where plants are usually grown in stacked layers or on vertically inclined surfaces, often goes hand-in-hand with hydroponics - plants grown without soil, with added nutrients.

Belgian company Urban Crops uses vertical installations that cultivate large crops, and its hydroponic technology is said to produce healthier, faster-growing plants in a more sustainable way, without pesticides or herbicides.

Daphne Ronse from Urban Crops says the firm's systems "are fully automated, robotised and can be integrated in existing industrial processing environments. We also develop our own plant growth recipes and have our own R&D on growth LEDs."

She adds that "installations we market are capable of producing up to 300 crops per square metre divided over a maximum of 24 growth layers per standard unit. Units can be placed next to each other using the same robotics and automation."

The systems have greater water efficiency (95 per cent less water than open field farming) and the installations can grow more than 160 types of crops, including lettuces and food herbs, root crops, flowers and medicinal crops.

Stephen Fry from HydroGarden, supplier of specialist hydroponic equipment, says that "although self-sustainability will need to play an increasingly prominent role [in urban areas], the issue of agricultural land being a finite resource remains a point of concern.

"This is where the idea of utilising brownfield sites comes into play. For example, there are countless industrial units across the country that remain unleased for several years. It's these types of unused buildings that provide the ideal location to establish an urban farm."

Another US company, Aerofarms, specialises in building farms that stack vertically or lengthwise to maximise space. Its ninth farm recently opened in Newark, New Jersey (NJ) and is billed as the largest indoor vertical farm in the world.

According to Aerofarms, the farms use 95 per cent less water than field farming and are "designed to combat the problem of 1.5 million acres of productive farmland lost every year to urbanisation in the US."

The NJ farm is 6500m^2 and could harvest almost 910,000kg of food a year. The smart 'aeroponic' growing system is a closed loop, misting roots of greens with water, nutrients and oxygen for faster harvest cycles.

Indoor farming doesn't only maximise space 'overground'. Growing Underground, a London-based company, uses former air-raid shelters to grow micro-greens and salad leaves 33 metres under the streets of Clapham. Its hydroponic systems use 70 per cent less water than open-field farming, employing LED technology to grow crops for wholesalers and local restaurants.

When we eventually run out of space for farming and people, we will probably have to look elsewhere in the solar system.

There has been a lot of talk in the last few years about people leaving Earth for another life - on Mars. Volunteers have even signed up to make a one-way trip to the Red Planet with the Mars One project.

In a recent Ask Me Anything session on Reddit, SpaceX founder and CEO Elon Musk said the first humans on Mars would “initially [use] glass panes with carbon fibre frames to build geodesic domes on the surface, plus a lot of miner/tunnelling droids.” He added that tunnelling robots “can build out a huge amount of pressurised space for industrial operations and leave the glass domes for green living space.”

So where to start? Well, one of the most important functions Mars inhabitants will need to undertake is growing nutritious food to survive, so naturally, Nasa is on the case. The space agency has been experimenting for some time, to see if cultivating crops on celestial bodies is actually feasible.

A team from Wageningen University & Research Centre in the Netherlands is carrying out trials to try and achieve high yields of green bean, radish, rocket, garden cress, spinach, pea, rye, carrot, tomato and potato grown in Mars and moon soil simulant from Nasa, and standard potting soil (the latter as control) in greenhouses.

Wieger Wamelink, senior ecologist and principal investigator of the project says earth-potting soil was used to “simulate digging-in of dead plant material from a previous harvest” and nutrient solution was added to “imitate human waste of future Mars and moon inhabitants.

“This is important, since nothing can be lost or wasted, especially nutrients for plant growth. Manure is manure, even when it originates from humans.”

Mars and moon soil contains heavy metals such as lead, mercury and chromium. Tomato, radish, pea and rye were tested first and the metal contents were far below the allowable dose, so were safe for human consumption.

Wamelink says the team will continue researching, with space farming in mind: “One of the experiments will be testing the effect of introducing bacteria on the Mars plants’ growth.”

When it comes to predicting the future, Wamelink is quite certain of what farming on Martian soil will be like: “Let’s assume that humans will arrive on Mars soon after 2030. The first years/decades of plant growth will be something to improve on.

“Crops such as strawberries will be particularly important as they protect humans from deadly cosmic radiation on Mars’ surface. Cultivation of potatoes will also be imperative, as it’s still our most energy-rich food that we can grow in large amounts on a small surface.

“In later periods, if we decide to really colonise Mars, all food will have to be grown in large underground domes under LED lights on the planet.”

Wamelink adds that meat will remain scarce, if not absent, since it would take an enormous amount of surface area to grow all the vegetables for animals to eat.

As well as soil, Nasa has funded research on greenhouses suitable for life on Mars, with promising results. Horticultural engineer Gene Giacomelli, director of the Controlled Environment Agriculture Centre at the University of Arizona and co-principal investigator for the project, says the greenhouse prototypes were "lightweight, compact, collapsible and deployable, with high productivity.

"The greenhouses run on recirculating hydroponic systems for control of the root zone, which means minimised labour, energy efficiency, recycled plant nutrients. They are derived from existing Earth greenhouse systems and are modified to meet the design requirements of another planet for Nasa."

As well as hydroponics, the greenhouses have "recirculating controlled environment air systems for regulation of aerial temperature, humidity, light and CO2. They also have computer-based monitoring and control, with decision-support system and crop management strategies developed for highly compact, fast turnover of crops," Giacomelli adds. "Combined in total, these [and other systems] create the Bioregenerative Life Support System needed for long-term establishment of living on another planet."

For over a decade, Giacomelli and the team have been working on this concept for Nasa. He says that one should think this Nasa project is really 'urban agriculture' for the future space city.

If we can make it work on Mars, the practices can then be applied to other areas where there are only slightly limited resources, compared to any site off-Earth.

Nasa has recently partnered with Florida Tech to trial 'Martian Gardens' with the aim of finding vegetables that could withstand soil from Mars. Ralph Fritsche, senior project manager for food production at Kennedy Space Centre, says that cultivating plants in alien soil is difficult, as Mars is covered with regolith - crushed volcanic rock containing toxic chemicals but nothing organic.

For the trials, 45kg of soil from Hawaii is being used, which has similar characteristics to Mars soil. In a pilot study, lettuce grown in Mars simulant showed germination rates about three days slower than the other plants. Fritsche says that hopefully, the experiments will provide control for future studies, when researchers try to grow radishes, Swiss chard, kale, Chinese cabbage, snow peas, dwarf peppers and tomatoes - all nutritious foods selected for astronauts.

Nasa already has Veggie (the Vegetable Production System), a deployable plant unit that has been on expeditions. The space agency has identified the need to improve human habitability aboard the International Space Station (ISS) due to long missions, so Veggie supplies crews with a sustainable source of fresh salad-type crops. It also supports experiments that establish how plants respond to gravity.

Veggie contains pillows with seeds inside, installed on to a root mat placed into the system's bellows. Power is applied and water is added to the mat to start germination. This process is continued until plants are harvested, then it is restarted.

According to Nasa's report, Veggie provides the largest volume available for plant growth on the ISS, and provides an improved understanding of plant growth and development that will be important for refining plant production on Earth.

Antarctica is one of the most hostile places on our planet. Many researchers venture there to gather data about the extreme environment around them and to keep the teams as healthy as possible, hydroponic farming in greenhouses is used for growing nutritious food, and it has been present there for the last couple of years. The University of Arizona's Controlled Environment Agriculture Centre customises its climate-controlled greenhouses for places like Antarctica, and Nasa's extensive research into growing systems could indeed be used for this kind of harsh climate.

It's an uncomfortable fact that only five per cent of the rural population in Africa have access to electricity. What's more unsettling is that only four per cent of farms in Africa end up irrigated.

Charles Nichols, CTO and co-founder of SunCulture, says that "because of this lack of access to electricity, most [African] farmers rely on petrol pumps or manual (treadle) pumps". The high energy costs and labour inefficiencies of these solutions lead to lack of irrigation, resulting in decreased yields and increased vulnerability to climate change.

SunCulture takes agricultural and renewable energy technologies that have been developed in other parts of the world and designs systems such as its AgroSolar irrigation kit, to benefit farmers in Africa.This uses a solar-powered pump with a high-efficiency drip irrigation system to make it cheaper and easier for farmers to improve crop yields and quality.

"Traditional drip irrigation solutions are highly water efficient out of necessity," says Nichols. "Yet they are complicated and expensive to transport and install, as each acre [0.4ha] system requires over 100 components transported by pickup truck, compared to only five in SunCulture's acre kit, which fits on the back of a motorcycle and can be transported anywhere in Kenya at nominal cost."

SunCulture's solar pumps replace expensive fuel ones to push water into a raised tank. Gravity then directs water through irrigation lines directly to crops, saving farmers water, labour and time. Nichols adds: "Switching to SunCulture's system increases a farmer's yields by up to 300 per cent and decreases water usage by up to 80 per cent."

He says that in the next year, SunCulture farmers will save 370 million gallons of fresh water, generate over 84,000kWh of renewable energy, and grow over $14m (around £11m) of produce. "The average farmer goes from making just $600 (£490) per acre, growing staple crops like maize with the rain, to making about $14,000 (around £11,500) per acre growing fruits and vegetables with irrigation," Nichols explained.
SunCulture also works with Syngenta to supply farmers with vegetable seeds that have been hybridised to thrive in Kenyan soil and climactic conditions. Nichols says: "We've found that with a

little ingenuity, it's possible to adapt technologies designed for developed agriculture markets to the needs of off-grid consumers."

As well as using solar power to help people prosper in harsh climates, UK company Seawater Greenhouse – in collaboration with researchers from Aston University – uses desalinated water from the sea to create better yields for African farmers.

"The greatest debilitating factor for farmers trying to grow crops in the Horn of Africa is that evaporation is much greater than precipitation," says Charlie Paton, managing director of Seawater Greenhouse. "Our process overcomes that by using seawater to produce cooler, cleaner and more humid air."

The greenhouses use photovoltaic technology, pumping saltwater from the sea to produce freshwater via reverse osmosis. The remaining water is then then trickled over a specially-designed cardboard structure, positioned adjacent to the wind direction, creating a cool, humid breeze that reduces transpiration.

Salt from the seawater is used in cooking and preserving. The seaweed and kelp, containing macro- and micro-elements needed for crop cultivation, are used for fertilisation of the greenhouses and surrounding areas.

Another company trying to solve the problem of farming in a harsh environment is the Centre for Agriculture and Biosciences International (CABI), a not-for-profit organisation that provides scientific expertise to solve agricultural and environmental problems. CABI has created a global programme called Plantwise, its biggest development project to date.

Dr Marin Hirschfeld, Plantwise communications manager, says it works "to increase food security and improve rural livelihoods by reducing crop losses.

"We're currently active in 34 countries in Africa, Asia and the Americas. We work with governments to set up networks of 'plant clinics', where farmers get practical plant health advice from trained experts." The clinics have access to the Plantwise Knowledge Bank, an online gateway with plant health information, such as diagnostic resources, pest management advice and pest data.

Hirschfeld says: "While it's not as trendy as space or urban farming, the farming undertaken by the smallholder farmers we support is certainly extreme. In many cases, they are subsistence farmers who completely rely on their farm for their food and income."

According to Hirschfeld, 79 per cent of farmers surveyed last year reported yield increases after visiting a plant clinic and 70 per cent reported an increased income.

Over half of all plant clinic recommendations involve non-chemical control methods, and a study in Thailand shows that pesticide use and money spent on pesticides have halved since Plantwise was launched in the country in 2013.

“The Knowledge Bank helps plant doctors diagnose the problem affecting the crop and recommends appropriate treatments,” Hirschfeld adds. “Last year we launched e-plant clinics – where the plant doctors are given Android tablets pre-loaded with the Plantwise Factsheet Library app, which means information is accessible offline, but is regularly updated whenever there’s a Wi-Fi connection.”

Through the e-plant clinics, they collect data every time a farmer visits a clinic. The farmers get a prescription via SMS text and the doctors get the data in a couple of days, instead of three months later. “As a result, we can track pest outbreaks practically in real time,” Hirschfeld explains. “For example, in Sri Lanka, a banana pest was first reported at a plant clinic last year. Thanks to the connectivity, local plant doctors were able to contact diagnostic experts in the UK and get identification and treatment advice the same day.”

Like CABI, organisations that share agricultural knowledge and better practices make people’s lives better and farming in harsh environments easier. Extreme farming certainly isn’t for everyone , though for some there is no choice. Yet if more institutes and companies help to make the world – or other planets – a little easier to live and farm in, humankind may be able to extend its stay a while longer.

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