Plants are essential for our lives and future

Hydroponics and the future of farming

Could hydroponic farming help solve food security issues?

With the world's population nearing 7.5 billion – and global prosperity and the desire for more resource-intensive foods rising steeply too – it's clear that farming needs to become more productive.

One way of meeting future food needs could be hydroponics – growing plants without soil, instead using a nutrient-rich solution to deliver water and minerals to their roots. It's already being used to increase farming outputs and grow plants in habitats that wouldn't normally sustain them.

Despite sounding like something out of science fiction, it's nothing new. The Aztecs built floating farms around the island city of Tenochtitlan, and the explorer Marco Polo wrote about seeing floating gardens during his travels through 13th-century China. By the 1930s, Pan American Airways had established a hydroponic farm on a remote Pacific island to allow its flights to top up with food en route to Asia.

Today farmers are slowly increasing their use of hydroponics, and researchers are looking more closely at how it could solve future food problems. In the future, some of its applications could be out of this world.

How does it work?

In conventional agriculture, soil supports a plant's roots – helping it to remain upright – and provides it with the nutrients it needs to grow. In hydroponics, plants are artificially supported, and a solution of ionic compounds provides nutrients instead.

The thinking behind this is simple. Plant growth is often limited by environmental factors. By applying a nutrient solution directly to a plant's roots in a controlled environment, a farmer can ensure that the plant always has an optimal supply of water and nutrients. This nutritional efficiency makes the plant more productive.

The solution can be delivered in a number of ways. A plant may be:

- placed in an inert substance (such as the volcanic glass perlite or rock wool) and have its roots periodically flooded with solution
- placed in an inert substance and rained on by a solution dripper
- suspended with its roots in the air, with these then sprayed with solution mist
- placed on a slightly sloping film that allows solution to trickle over its roots

All of these systems are mechanised in one way or another, usually using either a pump or a mister to deliver the solution from a separate store. The solution is also usually aerated to ensure that the roots are supplied with adequate oxygen. Mineral absorption requires energy, and is powered by respiration.

Is it difficult?

Running and maintaining a hydroponic system can be complex. Plants require over a dozen essential nutrients, with the optimal amount of each varying according to species, growth stage and local conditions, such as water hardness.

Plus, some nutrients get absorbed quicker than others, which can cause a build-up of positive or negative ions in the solution, affecting pH. This can then hinder the absorption of other nutrients – partly because their uptake is pH-dependent, but also because excess quantities of some will prevent the uptake of others. Too much ammonia, for instance, decreases calcium uptake. Too much calcium prevents magnesium absorption.

On top of this, some compounds react with one another to form substances that are harder to absorb, and so have to be provided separately. Hydroponic farmers have to have a firm understanding of how plants and nutrients interact, and must monitor their solutions closely and respond to any concentration changes. Their other option is to purchase expensive automated systems to do this for them.

Farmers also must protect their nutrient solutions from being contaminated with unwanted substances. Enclosing hydroponic systems inside buildings or greenhouses is a common way to do this. It also allows them to control and optimise other environmental influences on plant growth – such as temperature, light and CO_2 – to further increase yields.

When people talk about hydroponics today, at least in agriculture, they usually mean not just soilless growing alone but controlling all of these factors collectively. However, this combined practice is more accurately known as controlled-environment agriculture.

Pros and cons

Hydroponic farming is complicated, but for many farmers, the benefits outweigh the downsides.

Pros	Cons
Increased productivity Using nutrient solutions, artificial lights, heaters and other pieces of equipment, plants can be made to develop faster, produce larger yields and grow all year round.	**High set-up costs** Setting up a hydoponic farm requires a large amount of equipment, all of which needs to be purchased before the farm launches.
More eco-friendly Water in a hydroponic system can be recycled – at its most efficient a hydroponic farm only uses 10% of the water a normal farm uses. Because it's a closed system, nutrients don't leach away – an efficient hydroponic farm may only use 25% of the fertiliser a regular farm uses. Plus, eutrophication (dense growth of aquatic plants like algae caused by run-off of fertiliser) isn't a problem. Soil pests are non-existent, and in enclosed greenhouses natural predators can be used to control insect pests – next to no pesticide is required.	**Higher running costs** Many of the control systems – pumps, water purifiers, lights, heaters, etc – need to be powered, which costs money. In conventional farming, heat, light and (some) water is provided naturally for free.
Feasibility in areas not suited to traditional farming Its high water efficiency makes hydroponic farming possible in arid environments. Hydroponic growing trays can be stacked on top of one another, and plants can be placed closer side by side than they can in soil, making it vastly more space-efficient than traditional farming. Because nearly all environmental conditions can be controlled artificially, unconventional growing spaces can be used – uninhabited buildings, disused railway tunnels, etc.	**Vulnerability** Because they are mechanised, hydroponic systems are vulnerable to power failures. In systems where roots are highly exposed, unwatered plants can dry out rapidly. Nutrient and pH imbalances can build up far quicker in a solution than in soil; if something goes wrong, an entire crop can be wiped out very quickly. Likewise, water-borne diseases can spread quickly and widely, and water-borne microorganisms can contaminate solutions fairly easily.
Reduced transportation Crops can be grown away from their natural habitats and closer to consumers, reducing transport emissions and providing people with fresher goods.	**Need for monitoring** Although a hydroponic farm requires less effort overall (planting and harvesting is far less labour-intensive), hydroponic plants cannot be left to their own devices for long periods like regular fields of crops. A hydroponic farm

Pros	Cons
	must be regularly attended to by a farmer, or else automated.
Monoculture not a problem Farmers don't need to worry about exhausting their fields of certain nutrients through growing the same crop over and over – there is no need for crop rotation, so in-demand crops can be focused on.	**Need for expertise** Hydroponic farmers need to understand the technique, which is complicated.

Hydroponic crops

Theoretically, hydroponics can be used to grow any crop. However, the technique is mostly used with plants that grow efficiently under hydroponic conditions, such as salad greens, cucumbers, peppers and herbs. Most commonly it is used to grow tomatoes.

Farmers tend to use hydroponics with tomato varieties that have had special characteristics bred into them, such as bearing larger fruit and growing indeterminately (meaning that they grow continually, repeatedly producing fruit along their stems).

Disease-resistant varieties are also popular as they enable plants to live for longer and bear more produce.

On the other hand, crops that are not genetically suited to hydroponics are avoided, such as wheat. Research in the USA has shown that using the system to grow enough wheat to make a loaf of bread would cost $23!

Urban farming

The vast majority of plants are still grown using soil, but hydroponics is on the rise. In 2013, Thanet Earth – the UK's largest greenhouse complex, based in Kent – used controlled-environment agriculture to produce around 225 million tomatoes, 16m peppers and 13m cucumbers, which equated respectively to 12, 11 and 8 per cent of Britain's entire annual production of these crops. It currently operates four greenhouses, and has plans to build another three.

Globally, it was estimated that the hydroponic farming industry was worth $21.4 billion in 2015, with its value projected to grow at 7 per cent per year. Slowly but steadily, farming appears to be changing.

But equally, there are big global changes on the horizon, and these could vastly accelerate the use of controlled-environment agriculture. By 2050, an extra 3bn people could be living on Earth, with over 80 per cent of the global population living in urban centres. We're already using the vast majority of land suitable for raising crops, so new growing areas – particularly in arid regions – need to be found.

One much-talked-about solution is vertical urban farming – creating stacked hydroponic farms inside buildings, including tall skyscrapers. This would solve the problem of running out of available farmland, and also place farms right at the heart of where crops are needed – our densely populated cities of the future. Vertical farms are already being built in Michigan and Singapore – and even in disused bomb shelters in south London.

And, as it plans human space missions that will travel further and further from Earth, NASA is investigating whether hydroponics could be used to create space farms to feed astronauts. Working with the University of Arizona, it is seeing whether it can create a closed-loop system that feeds human waste and CO_2 into a hydroponic farm to create food, oxygen and water.

QUESTIONS FOR DISCUSSION

- Different hydroponic set-ups are preferred in different scenarios. Why do you think a farmer might prefer to use one system over another?
- What other advantages and disadvantages of hydroponic farming can you think of?
- Hydroponics is also often used to illegally grow cannabis. Why do you think this is?

Developing dwarf breeds of plants

Much of the wheat you eat comes from dwarf breeds. Read on to learn how these are developed, links to other foods and the pros and cons of growing them

Dwarf breeds are varieties of plants that are smaller than normal for their species. They stay small because they produce lower levels of certain hormones – often called growth factors or growth substances because of the role they play in development.

Gibberellins, one of the five major classes of plant hormones, cause a plant's stem to grow longer. Because of a genetic mutation, dwarf plants produce less gibberellin and their stems do not grow as long as normal.

The benefits

Between the 1930s and late 1960s, the technologies used in farming dramatically improved. This significantly increased worldwide food production and saved a huge number of people from starvation. One of the most important developments was that scientists bred rice and wheat plants that produced more food. Many of these plants were either dwarf breeds or semi-dwarf (smaller than normal but bigger than dwarfs).

Wheat plants were bred to absorb more nitrogen from the soil and grow larger ears of grain. However, these large ears were too heavy for the plants' long stems, causing them to bend until the grain touched the ground. The wet soil would spoil the wheat. An American biologist called Norman Borlaug discovered that he could selectively breed semi-dwarf plants with shorter stems. This made them more stable and able to support the larger ears of grain.

The shorter stem also requires less energy from photosynthesis to grow, meaning the plant devotes more energy to growing the grain. The same is true of nutrients from the soil, which increases the effect that fertilisers have on the amount of grain produced by each plant.

Borlaug's discovery doubled the amount of wheat produced by Pakistan and India between 1965 and 1970 and greatly improved food security across the world. He was awarded the Nobel Peace Prize in 1970 in recognition of his contribution to world peace through increasing food supplies.

Apple orchards today contain trees that are almost all dwarf or semi-dwarf. This makes the fruit easier to pick and reduces the distance nutrients have to travel from the roots up to the leaves and buds.

The dwarf trees in orchards are often made using grafting. Grafting is a technique where the tissue from one plant is inserted into another. Often, fruit trees are made by grafting together the parts of three different plants: onto the trunk from a dwarf plant are grafted roots with good stability and resistance to diseases in soil, and branches from a plant which produces the best fruit. This produces a tree with the best characteristics from all three plants.

Rice is one dwarf variety being investigated for use by astronauts to grow food in space. Others include wheat, tomatoes, peppers, soybeans and peas.

One of the many challenges that space agencies have to overcome if they want to send astronauts further than ever before is providing food for these longer missions. Rather than sending ready-made food, it would be more efficient if astronauts could grow their own food in the spacecraft. Plants could also be used to purify water and recycle carbon dioxide to oxygen. Dwarf breeds are well-suited to being grown on spacecraft because they need less room to grow than standard plants.

Developing dwarf breeds

Whether they're grown on Earth or in space, scientists can use selective breeding and genetic engineering to develop plants with defective gibberellin genes.

Selective breeding is an ancient method for develop plants (or animals) with particular traits. Breeders choose two parent plants with desirable characteristics and make them reproduce. The parent plants' DNA is passed on to the offspring, along with the characteristics. Dwarf breeds can be developed over many generations by breeding parent plants that produce relatively low amounts of gibberellin.

Since the 1970s, scientists have been able to alter organisms' DNA directly using genetic engineering. Genetic engineering is a set of techniques which includes: copying a piece of DNA from one organism and inserting it into the genome of another; removing specific genes from an organism's genome; or causing a particular gene to mutate. Genetic engineering is now used to produce dwarf plant breeds.

Dwarfing can also occur in nature if a plant's environmental conditions aren't to its liking. The type of conditions that can limit how large a plant grows are poor soil, low light, drought, cold or infection. Plants that have been dwarfed due to environmental conditions are said to be stunted.

The downsides

Dwarf breeds of crops are typically grown in monocultures, meaning a single breed or type of crop is grown on a specific piece of land. Because dwarf plants have been bred and selected for their specific characteristics, it makes sense to only grow the species and breed best suited to a particular location. Dwarf plants are also less able to compete against other plants for light, because they are shorter.

There are advantages to monocultures. For example, they make planting, maintenance and harvesting simpler and therefore cheaper. They also can produce more food from a specific piece of land over the short term. However, there are also disadvantages.

Different breeds need different nutrients. Growing only one breed in a particular location means some nutrients are used up more than others. This can lead to the soil running low in particular nutrients, forcing farmers to use chemical fertilisers.

The single breed grown in the monoculture may also be particularly susceptible to a certain pest or disease. These can spread more quickly in monocultures because every plant is affected by them. To prevent this, farmers may be more likely to use pesticides on monocultures – which can be expensive and also cause pollution.

If multiple breeds are grown alongside each other on a piece of land, this is called a polyculture. Polycultures are more difficult to plant, maintain and harvest. However, they make the best use of all the nutrients in the soil and reduce the crops' susceptibility to disease and pests – which means a more secure supply of food. Polycultures also increase biodiversity in the area, and many experts believe polycultures are more environmentally friendly.

QUESTIONS FOR DISCUSSION

- What would happen if a plant produced more than the normal amount of gibberellin and when might this be beneficial?
- What is another example of selective breeding in plants? What about in animals?
- What other characteristics would suit plants grown in space?
- What other technological advancements have made agriculture more productive since the 1930s?
- Why is genetic engineering controversial?

Transgenic crops

Modifying the genetic make-up of a plant can improve crop yields or resistance to pests

Since the first genetically modified (GM) crops went on sale in 1996, areas planted with these crops have increased by around 3–4 per cent a year and in 2014 covered at least 1.8 million square kilometres, an area roughly twice the size of France.

GM crops may be controversial – because they contain DNA that has been modified by humans adding DNA from other species – but they hold the potential to solve many of the problems facing modern agriculture, such as the rapidly changing climate and soaring human population. Genetic engineering can not only improve crop yields more rapidly than traditional crop-breeding techniques but also alter crops by introducing genes from completely unrelated species, such as bacteria, to create transgenic plants.

Crops already approved for use in the USA include soy modified to be more tolerant to the weedkiller glyphosate and pest-resistant maize, known as Bt corn, that kills rootworm. Bt corn includes a gene from the bacterium Bacillus thuringiensis which allows it to produce a toxin that kills the rootworm. It now makes up 75 per cent of maize harvested in the USA. However, the continued use of Bt is threatened by rootworm populations that have adapted to resist the toxin. In the state of Iowa, resistance is already rife.

The next generation of GM crops may be plants with altered levels of nutritional components such as oils, proteins and starch, or with increased resistance to drought or salt. These types of crops are already being tested in field trials. But GM crops aren’t embraced everywhere: Scotland announced plans to ban the growing of GM crops in 2015.

Fuel the world

Harnessing plant energy reduces our reliance on fossil fuel

Fossil fuels will eventually run out. However, alternatives that rely on today’s plants are in plentiful supply. Ethanol is an alcohol fuel that can be produced from corn, sugar or wood by fermenting the starchy or cellulosic parts. Most US ethanol comes from corn, whereas Brazil uses sugar cane to make the ethanol in its gasohol blend (25 per cent ethanol, 75 per cent gasoline). The problem with these biofuel crops is that they take up scarce land that could otherwise be used for growing food.

Other plant-based power options include a recent University of Cambridge project harnessing soil bacteria in walls made from synthetic material and living plants. In the process, the bacteria release electrons that can be channelled into an electrical circuit. The team of scientists produced a prototype green bus shelter powered by plants. There are also some solar panels that use plant-inspired pigments and dyes to harness the sun’s power.