Sophie Harrington

Gardens in the sky

Growing plants in space

Thinking of space science conjures up images of planets, stars, and sleek spaceships cruising through the galaxy. But humans aren't the only life forms we're sending into space. As ***Sophie Harrington*** *explains, some of the most cutting edge plant-science research is being carried out hundreds of kilometres above our heads.*

Missing gravity

The presence of gravity is a given for life on Earth. It's no surprise that many organisms use this ever-present force to guide their growth and development. Plant growth is highly directed by gravity, as roots grow downwards while shoots reach up towards the sky, in the opposite direction. These are known respectively as *positive gravitropism* and *negative gravitropism*. This response to gravity is crucial in directing plant growth down on Earth, but up in the International Space Station (ISS) it's another story.

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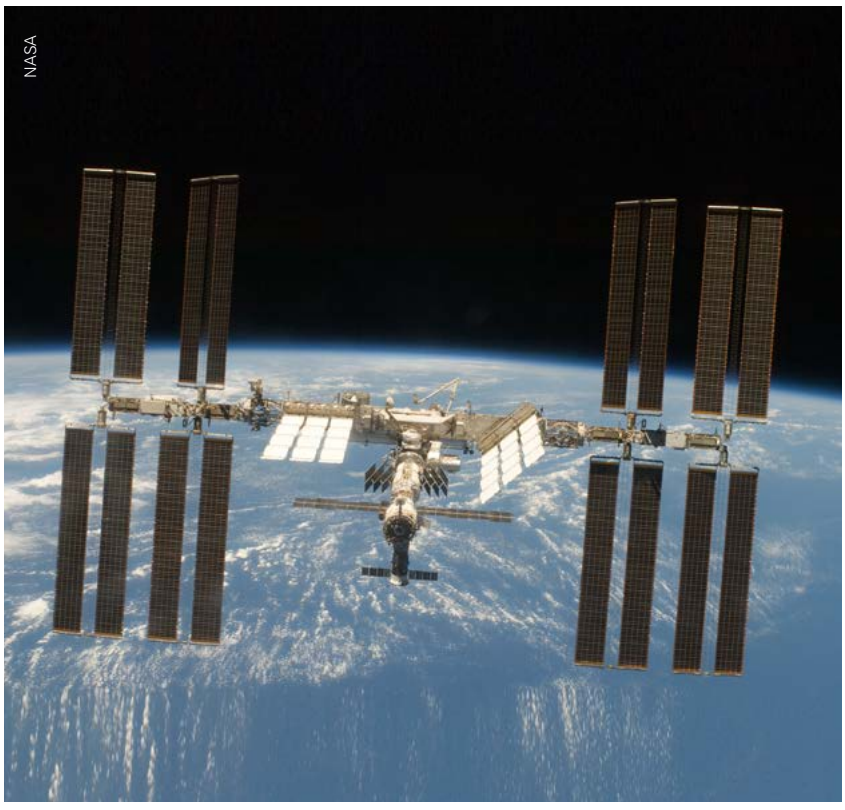
In orbit over 300 kilometres above the Earth, the ISS experiences only microgravity. The gravitational force from the Earth holds the station and its contents in orbit, so that everything inside experiences zero gravity (sometimes known as microgravity). But if gravity is so important, how do plants manage to grow properly on the ISS?

It turns out that plant responses to light, known as *phototropism*, may be just as important as gravity in determining how plants grow. Plant responses to light go in the opposite direction to gravity, with shoots growing towards the light (positive phototropism), while roots grow away (negative phototropism). It appears that on Earth both light and gravity play a role in directing plant growth. This also explains why, on Earth when seeds are germinated in a dark room, the shoot still grows up and the roots down. In that case, gravity is sufficient to determine the direction of plant growth.

Intriguingly, studies on the ISS suggest that the response of plants to different wavelengths of light may change in microgravity. Red light was found to promote plant growth on the ISS, while it doesn't back on Earth. It may be that the red-light response is suppressed on Earth by gravity, only appearing when plants don't perceive any gravitational force. This result was a big surprise to scientists who had originally thought that only blue light could direct plant response to light.

By studying plants in microgravity, researchers are able to remove gravity from the equation. Hopefully this will lead to even more discoveries about how light and other environmental cues interact with gravity (or the lack of it) to influence plant growth both on Earth and in space.

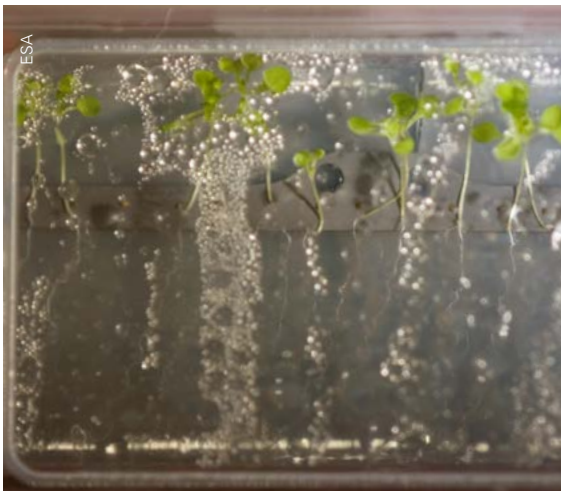


The International Space Station in orbit.

Growing up in space

Any plans to send humans into space for long periods of time will require the ability to grow plants to supplement the astronauts' diet. However, until recently, scientists weren't sure how microgravity might affect the life cycles of plants. It's not much good sending all sorts of seeds into space if they aren't going to grow properly.

Arabidopsis thaliana, a small garden weed, is the favoured plant for many scientists in part due to its short lifecycle. This makes it particularly suited for studying how life in space might affect its growth. Luckily for the astronauts, the little plants were able to grow quite normally in space. In fact, not only did their leaves, flowers, and fruit develop normally, but the leaves remained dark green for longer than they would on Earth. This suggests that microgravity may somehow influence leaf senescence, slowing plant ageing. Scientists still don't know what's behind this peculiar result, or if it also occurs in other plants. Even more intriguing is the question of whether humans and animals might also benefit from a visit to space. Perhaps the fountain of youth is actually in outer space.



Plants growing on the ISS need to use as little space as possible. Here Arabidopsis *seedlings are growing in a small dish, testing the effect of microgravity on root and shoot growth.*

The next step in growing plants sustainably in space is making sure they can produce seeds in space, and that these 'space seeds' can in turn germinate and grow themselves. A study by NASA attempted to grow *Arabidopsis* from seed to seed on the ISS. When the second generation seeds were sent back to Earth and germinated, the plants didn't show any visible abnormalities, boding well for the future.

Further work by Russian cosmonauts with pea plants showed that four generations of the plants could be grown on the ISS without any significant changes from the original. This suggests that microgravity and other space conditions do not affect the reproductive ability of at least some plants. It's looking more and more likely that astronauts will one day be able to significantly supplement their diet with home-grown vegetables and fruit.

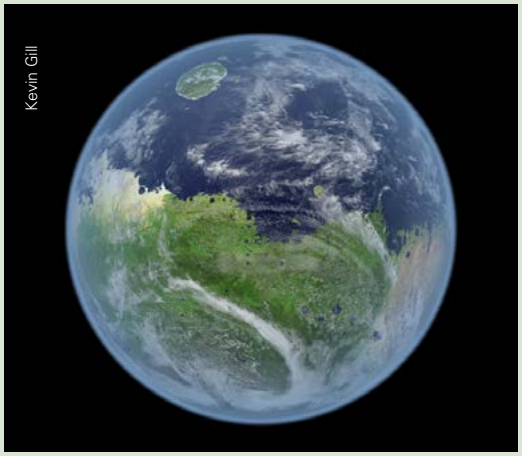
A green future for Martian exploration

Sending humans to Mars is a big operation, with public agencies like NASA and the European Space Agency as well as private groups such as Mars One working to make it a reality. But sending humans to Mars is going to need more than just a big rocket.

Feeding new colonists on the red planet will likely rely on easily-assembled greenhouses shipped with the astronauts to Mars. In these, colonists will be able to grow vegetables such as tomatoes and peppers to supplement their long-lasting, pre-packaged space food. Besides tasting good, these plants will provide needed nutrients to the colonists.

Future colonists on Mars will cultivate a variety of vegetables and fruits to supplement their diet. It will be a long time, though, before colonists can become self-sufficient. Early missions are likely to depend on biennial deliveries from Earth.

Most plans for colonies on Mars expect to use hydroponic systems to create their gardens. Some scientists, however, are exploring the ability of plants to grow on Martian soil. This would be crucial for an expanding colony, reducing the need for increasing greenhouse capacities. In fact, a recent paper suggested that many plants grow even better on Martian soil than they do on Earth soil. Perhaps the Red planet could one day be even greener than our own.



An artist's interpretation of how a fully terraformed Mars might look

In early plant experiments on the Mir space station, Russian cosmonauts found that their favourite time of day was tending to the plants. Gardening helped the astronauts unwind, with many becoming very attached to their plants. More recently, NASA astronaut Don Pettit (shown here) even started writing a blog from the point of view of the courgette plant he was tending to. That's dedication!

One small step for a plant

We know plants can grow in space, but what about on other planets? Researchers have been doing work simulating Martian and lunar conditions on Earth (see Box on left), but it's hard to study the Moon when we're stuck on Earth.

Luckily for us, NASA is about to send a miniature greenhouse to the Moon, filled with *Arabidopsis*, basil and turnip seeds. If all goes to plan, in late 2015 these will be the first plants to grow on a different world. Researchers will follow the growth of the plants for 5-10 days, comparing their growth to that of the Earth-based controls.

The Lunar Growth Module will hitchhike to the Moon on a rocket sent up by a private space company.

By sending these seeds to the Moon, scientists hope to discover whether plants would be able to germinate and respond appropriately with the different environmental signals on the Moon. While the first experiment will focus mainly on germination and phototropism, if all goes to plan more experiments will be flown to the Moon. As plant growth is studied for longer periods, the effect growing on the Moon has on sexual reproduction, dominant and recessive traits, and multi-generational growth amongst others can be studied.

Who knows – it might not be too long before all sorts of plants are growing on different worlds and in outer space.

Sophie Harrington is a final-year undergraduate at the University of Cambridge studying plant sciences