Science Societies

To boldly go

Recycling deep space waste to grow food on other planets

By Freda Kreier

May 20, 2025

Astronaut Kayla Barron checks out chile peppers growing inside the International Space Station. Photo of Kayla and the Earth courtesy of NASA (under this license https://creativecommons.org/licenses/by-nc-nd/2.0/deed.en). Background space image courtesy of Adobe Stock (Iuliia Sokolovska).

- Scientists are investigating how human waste can be treated and used to grow food on other planets, a crucial step for sustaining astronauts during long-term missions to the Moon and Mars.
- Research shows that while human-derived nitrogen can support plant growth, it is less effective than commercial fertilizers and requires treatment to be safe and beneficial for crops like lettuce.
- Developing efficient nutrient recycling systems in space could improve sustainability in agriculture on Earth by reducing fertilizer waste and greenhouse gas emissions while also supporting astronaut health and morale on deep-space missions.

Food is one of the biggest challenges faced by explorers. It’s certainly the first and most lasting issue faced by Mark Watney, the fictional NASA astronaut who is left for dead on Mars in the science fiction novel *The Martian*. Faced with the reality that his rations will run out before rescue, Watney makes the bold decision to grow potatoes on an alien world. However, the Martian soil is barren—free of the microorganisms and nutrients plants need to grow.

So, to survive, Watney plants potatoes in a slurry of rock and his own feces.

The Martian is a work of fiction. But real scientists are exploring the idea of using human waste to grow food on other worlds. At CANVAS 2024 in San Antonio, TX, researchers at Utah State University presented NASA-funded research exploring how nitrogen extracted from human waste stacks up to other forms of fertilizer—one of the many questions that must be ironed out before astronauts can expect to become farmers.

The stakes for space agriculture are high. NASA is planning human missions to the Moon and Mars in the coming decades. Getting supplies to these crews will be harder than any space mission since Apollo II. Finding ways to reliably recycle nutrients so that astronauts can grow their food out in space is mission critical. And so far, research shows that—at least for nitrogen—the solution won't be as simple as mixing up a fecal slurry.

"Recycling is the name of the game" for future flights, says Noah Langenfeld, a Ph.D. student at Utah State University who presented the research and a member of ASA, CSSA, and SSSA. "Not only is it more sustainable, but it's going to save us a lot of money in the long run."

“Recycling is the name of the game. Not only is it more sustainable, but it’s going to save us a lot of money in the long run.”

Bruce Bugbee (left) and Noah Langenfeld (right) from Utah State University discuss optimizing plant nutrition in wheat bred for growth conditions on the International Space Station. Photo by Bronson Teichert.

A short history of night soil

There's nothing new about using feces and urine as fertilizer. Nitrogen is one of the key nutrients plants need to survive. Farmers have historically shored up their nitrogen supplies using manure from livestock. Today, "most crops are limited by nitrogen availability," says Simon Gilroy, a professor of botany at the University of Wisconsin–Madison.

Humans, too, have also proved to be a reliable source of nitrogen—though their contributions are euphemistically called "night soil." "Humans happen to be nitrogen balanced," Langenfeld explains. "The amount of nitrogen we eat on a daily basis is approximately equal to the amount of nitrogen we excrete."

This fact was the basis behind one experiment run by Roscosmos—the Soviet Space Agency—during the 1950s and 1960s. Russian scientists attempted to recreate the conditions of more extended space missions by creating isolated chambers that crew members would live in for weeks if not months. These chambers grew crops for the crew, which were partly fertilized by their own urine. However, researchers soon realized that human urine, which contains up to 95% of all excreted nitrogen in the human body, was too salty for most plants to handle (feces contain the other 5%). These scientists concluded that real space travelers would need to remove salt from their waste before using it to grow food.

A chile pepper is pictured suspended in weightlessness inside the International Space Station. Photo courtesy of NASA and reproduced under this license: https://creativecommons.org/licenses/by-nc-nd/2.0/deed.en.

Following these early experiments, it wasn't until the advent of the International Space Station in 2000 that space agriculture took its next big steps. The presence of a permanent station in orbit suddenly allowed scientists to run long-term experiments on plants growing in microgravity. In 2015, astronauts ate their first food grown in space—some red lettuce leaves. The ISS has since been home to chilies, other leafy greens, and a few radishes.

These microgravity experiments have opened the world of space agriculture. "Just a few years ago, there were big questions about whether you could even grow a plant in space," Gilroy says. But these studies are only the first steps in NASA's larger plan to grow plants on an alien world. Most space agricultural projects are planned for permanent bases on planetary surfaces where even the slight gravity of the moon could make a major difference in growing food, says Gioia Massa, senior scientist in space crop production at NASA's Kennedy Space Center.

NASA experiment studying the growth of radishes on the International Space Station.

Recycling nitrogen

One of the big questions researchers are now facing is how to ensure that plants far from their home planet have access to all the nutrients they need to survive. On Earth, nitrogen-fixing bacteria convert nitrogen in the atmosphere into biological forms of the element that plants can use. This nitrogen gets recycled throughout the ecosystem.

Mars does not have a nitrogen atmosphere (Mars's atmosphere is only 3% nitrogen compared with Earth's 78%) or nitrogen-fixing plants. All the nitrogen that astronauts will have access to will have to be brought with them. Farmers typically re-up the nitrogen supply in their fields using manure or commercial fertilizer. This is a harder sell during space travel. For one thing, sending fertilizer up into space is expensive. "We can't be spending a million dollars to grow one plant," Langenfeld says.

Artist's concept depicts astronauts and human habitats on Mars. Image courtesy of NASA/JPL-Caltech/MSSS.

Then there's the fact that space agencies will have to coordinate the drop-off of fertilizer over the vast expanse of space. So instead, NASA is working on making deep space missions more efficient, accounting for every atom in and every atom out, Massa says. For nitrogen, recycling human waste will "become increasingly necessary," she says.

Step one is discovering how well plants respond to nitrogen from human waste. This was the main question behind Langenfeld's Ph.D. research. For several years, Langenfeld grew lettuce fertilized with different forms of nitrogen meant to mimic how plants get their nutrients on Earth. Some plants received forms found in commercial fertilizers. Others were grown in urea—the nitrogen-rich compound found in urine. A third group received fertilizer from dead nitrogen-fixing bacteria.

Commercial fertilizers are tailor-made to boost plant growth. Indeed, lettuce grown using this form of nitrogen thrived. Urea-grown lettuce, not so much. "The plants grew, but they didn't grow quite as well as if we had 100% reagent-grade chemicals," Langenfeld says.

This first round of experiments reveals that even without the issue of salty urine, human waste isn't an ideal nitrogen source for plants. Put another way, Watney's potatoes "would have grown, but they wouldn't have been optimal," Langenfeld explains.

Future flights

This doesn't mean that astronauts won't be using their own waste to fertilize crops during future space missions. Instead, Massa says that this research suggests that astronauts will probably have to treat their waste before applying it to their crops, both for plant health and human safety. This might mean chemically converting urea into a form of nitrogen that plants like better.

Human waste isn't an ideal nitrogen source for plants. ... Watney's potatoes "would have grown, but they wouldn't have been optimal."

Similar biological systems occur on Earth. The hard part is replicating these systems in space. "Trying to customize what's evolved over millions of years [on a smaller scale] is a great challenge," Massa says. "I think we can do it, but it will take a lot of work."

Why invest so much time, energy, and money into growing food in space? There are a variety of reasons, Massa says. Plants provide whole-food nutrition that astronauts will need during deep-space travel. NASA has also found that astronauts report better mental and physical health while working on plant projects on the ISS.

NASA astronauts Jessica Watkins and Bob Hines test soilless hydroponic and aeroponic methods to grow plants. Photo courtesy of NASA (reproduced under this license: https://creativecommons.org/licenses/by-nc-nd/2.0/deed.en).

"Astronauts tend not to eat enough. It's like eating plane food all the time," Gilroy says. NASA hopes that fresh fruits and vegetables on longer-term missions will create enough variety that astronauts will eat and stay mentally fit. On the ISS, astronauts have already noted that fresh produce is "a big deal," Gilroy says.

Advances in space agriculture could one day benefit farmers back on Earth. Research suggests that around half of nitrogen applied to fields is lost into the atmosphere or into waterways where it contributes to eutrophication. Meanwhile, the nitrogen-making industry currently contributes around 2% of all greenhouse gas emissions every year. Making nitrogen recycling more efficient in space, "could be a big benefit" to Earth, Langenfeld says.

Those advances may be a long way off. Scientists have only studied space agriculture for the last 70 or so years. "That's a short period of time to work out what happens in such a weird environment" compared with the thousands of years humans have grown food on Earth, Gilroy says.

Massa is hoping to learn more during the upcoming Artemis III missions. She is part of a team putting together a payload called Lunar Effects on Agricultural Flora (LEAF) to grow microgreens, *Arabidopsis*, and duckweed on the lunar surface. If manifested for flight, the project will help astronauts and scientists understand how plants will handle lunar radiation, gravity, and the lower pressure systems of space stations.

Researchers like Massa think it's only a matter of time. "Whenever humans have explored throughout history, they've brought plants they need with them," she says. "I don't think it'll be any different for space exploration."

Dig deeper

View the presentation, "Nitrogen Recycling for Bioregenerative Life Support," by Noah Langenfeld at CANVAS 2024: https://scisoc.confex.com/scisoc/2024am/meetingapp.cgi/Paper/158164.
