The idea of exploring space, including extended human missions and the potential for future bases on the Moon, Mars, or elsewhere, is not just science fiction. With the recent release of the book and movie *The Martian*, the current Hawaii Space Exploration Analog and Simulation (HI-SEAS) mission featured on the *New York Times* The Daily 360 video channel (https://nyti.ms/2mrbQDY), and talk from NASA and SpaceX about sending humans to Mars, many people are asking, “What’s possible?”

Among those were attendees of last November’s ASA, CSSA, and SSSA International Annual Meeting in Phoenix, AZ, who filled a room on the final day of the conference to hear talks during a session titled, “New Frontiers of Soil and Plant Sciences: Astropedology and Space Agriculture.” Organizers Jim Bell, Professor in the School of Earth and Space Exploration at Arizona State University, and Hangsheng (Henry) Lin, Professor of Hydropedology and Soil Hydrology at Penn State, brought together individuals with diverse research backgrounds to present research from fields including planetary science, soil science, and plant physiology.

Deep space exploration will require collaboration from across many disciplines. And, Lin says the excitement surrounding space may also be an opportunity for “public outreach and getting the public excited about [Earth science and] how we should really treasure what we have and treat the stuff underneath our feet very carefully and wisely.”

### Extraterrestrial Soils

The terminology used to describe soil takes into account its inherent biological processes. However, the term “soil” has been borrowed to describe compounds that lack a living component.

“The astronauts go to the Moon, and they’re kicking around this fine-grain material that looks like soil, and we drive rovers on Mars, and they’re leaving their rover wheel tracks in this fine-grain material that looks like soil,” Bell says. Thus, the term “soil” gets used in these situations even though it might be more appropriate to describe the material observed on other planetary bodies as regolith. “In the planetary science world, we start calling them lunar soil or Mars soil, and we just use that term because we’re talking about fine-grain materials that are created physically and chemically, ground down from the parent rock just like Earth soils are,” Bell says.

Some soil scientists like Lin don’t necessarily take issue with using the term “soil” to describe these materials. “Indeed, for a number of soil scientists including myself, our perspective is that soil evolved over time. In the early stages of soil evolution on Earth regardless of soil type, regardless of what part of the planet Earth, [soils] did not necessary involve life to begin with,” he notes.

Having some flexibility in the terminology and describing Martian regolith in terms of soil may be helpful for planetary scientists talking to soil scientists. “[Planetary scientists] don’t have the luxury that [soil scientists have] of being able to go out in the field, stick a shovel in the ground, dig a trench, make a profile, and take samples back to the lab,” Bell says. However, they can learn from what terrestrial soil scientists are doing and use soils on Earth as analogs for Martian regolith.

SSSA member Briony Horgan, Assistant Professor of Planetary Science at Purdue University, is doing just that. Data from the Curiosity Rover showed that Martian soils at Gale Crater had poorly crystalline phases. The crystallinity of soils indicates structure, and some soils on Earth have similar properties.
Horgan describes how on Earth, soils with poorly crystalline phases are found in climates that have monsoon seasons, are above the snowline, or are at sites where glacial weathering is occurring. For Horgan, and others using Earth soils as an analog for Mars, studying processes on Earth today is a way to develop hypotheses for what conditions were like on Mars in the past. In this case, these poorly crystalline phases indicate not just the presence of water on Mars, but how that water was likely moving through the soil.

In addition to providing insight as to how Martian soils formed, understanding the current state of these soils will be important for manned missions. For example, knowing the details of the physical, chemical, and mineral properties of Martian soil could provide important information needed by engineers to design systems that can extract critical resources like water, oxygen, or metals.

Agriculture in Space

If future plans include having a base or colony on Mars (or other worlds), those explorers will need to be capable of growing food due to the costs associated with sending supplies from Earth to Mars. Seeds have less mass to transport than prepared foods, but one has to consider the environmental differences between Earth and other planets before food can be successfully grown.

For example, on Mars, there are lower temperatures, extreme aridity, increased radiation, and lower gravity.
Bruce Bugbee, Director of the Crop Physiology Laboratory at Utah State University and a member of ASA, CSSA, and SSSA, points out that with little atmosphere, any building on the surface would be exposed to high radiation and damage from micrometeors. Given these conditions, it will take more than a sturdy greenhouse to establish crops. It is more likely that humans on Mars would be growing crops below ground.

Perhaps that is not that great a challenge, however, since there is already technology used on Earth and the International Space Station (ISS), which can regulate temperatures, gases, irrigation, and light to grow plants. Indoor crop production facilities and current ISS growing operations typically use LED lights, “but on Mars, we are now looking at parabolic mirrors and fiber optics to bring the light into the plants,” Bugbee says. The use of fiber optics technology to transmit sunlight has been proven, but it is so expensive that few people would use it on Earth. However, the cost of transporting and powering LED lighting on Mars would likely be greater than the costs associated with establishing a fiber optic cable network.

There are several ways these underground crop production facilities could be set up. One option is to use hydroponics systems, technology in use today that could be adapted for cropping systems on Mars. A second option would be to use Martian regolith as a growing medium. SSSA member Doug Ming, Soil and Planetary Scientist at NASA’s Johnson Space Center in Houston, has investigated the chemical makeup of both lunar and Martian soils with plant growth in mind. He points out that compared
Growing Plants in Microgravity

Researchers can expose plants to a wide range of experimental conditions here on Earth, including radiation, different atmospheric conditions, and extreme temperatures. Learning about how differences in gravity will impact plants often requires experiments to leave the surface of the planet.

One opportunity for observations is on a reduced-gravity aircraft that does parabolic flight patterns to provide short periods of weightlessness. Robert Heinse, a soil physicist at the University of Idaho, became interested in the effects of microgravity as a grad student at Utah State. Heinse, an SSSA member, ran several experiments on reduced-gravity flights. On these flights, he says, “You’ve got a nice experiment where you’ve got zero gravity . . . and then you get slammed with almost twice the Earth’s gravity,” limiting data collection to short bursts of time.

Fortunately, many official and unofficial experiments have taken place with plants in space. Soviet cosmonauts were growing flax aboard Salyut 1, the first space station, in 1971. Since then zinnias, soybeans, zucchini, lettuce and more have been grown, harvested, even consumed in space.

“One of the major challenges [in] these little space greenhouses was that these plants were starved for oxygen at their root zone” Heinse says. To find ways to avoid these hypoxic conditions, researchers needed to look into how liquid and gas distribute in soil in microgravity.

When growing plants in microgravity on a space station, everything needs to be enclosed—there cannot be soil media or water escaping. Getting water to the roots was not the problem since it could be delivered via membranes. Without gravity, though, capillary forces dominate the distribution of water, and the liquid becomes dispersed throughout the medium, as opposed to filtering through to the bottom as you would observe on Earth. This dispersal is a problem for gas exchange.

“You can either have oxygen moving through a pore or you can have water in the pore,” Heinse says. “You can’t have both.” Liquid-filled pores limit the exchange of gas, both oxygen getting to roots and metabolic gases leaving the root zone.

To maintain open pathways for gas exchange, you need to change how water is delivered. To keep liquid from diffusing throughout the growing medium, a light suction can be put on the source. This leaves more pathways open for gas exchange. Another approach is to change the growing media.

“What we found is that it’s probably a more forgiving environment to go with a slightly larger particle size distribution compared with a smaller one,” Heinse says.
with lunar soils, “Mars actually has more of the elements that are necessary for plant growth.” But soil tests have also revealed potentially harmful compounds in Martian regolith.

For example, the Phoenix lander revealed perchlorates in samples from the surface of Mars. Perchlorates, which are salts derived from chlorine, interfere with thyroid function in humans. Given that plants can take up these compounds, researchers have many unanswered questions. How concentrated will perchlorates be in plant tissues? Could the levels cause thyroid problems in humans? “These are questions that our NASA toxicologist asks me quite regularly,” Ming says.

These questions about exposure are important, especially when considering how much of a person’s diet could be made up of plants grown on Mars. If the goal is self-sufficiency, eliminating the need for food to be supplied from Earth, those on Mars will need to grow a wide variety of crops, from grains to greens. If even trace amounts of harmful compounds, like perchlorates, are taken up by these crops, it could lead to dangerous levels of exposure.

Beyond Nutrition

Providing a source of food is the main reason to grow crops, but agroecosystems would also provide services like water and air filtration. “[Soils] can purify water for reuse and [can be] engineered for waste treatment in space,” Lin says, while plants can provide filtered water and oxygen.

Life support systems tested at Johnson Space Center in the 1990s into early 2000s used plants for air purification. Researchers were even able to run these experiments with humans in the system. Ming recalls while working on these projects that the engineers were surprised how “reliable and how efficient the plants were, for example, in converting the CO₂ back into oxygen. It was just stunning.” The plants were more efficient, and had less potential for mechanical problems, than engineering solutions like CO₂ scrubbers.

There are also mental health benefits to be gained from plants. Growing crops would provide a meaningful source of work. And, having green, living vegetation in an otherwise barren landscape may reduce stress. “We’ve had lots of psychological evidence that plants are really important to the people,” Bugbee says. Anecdotally, most people who have spent time isolated in space seem to enjoy interacting with plants and often check experiments more frequently than is scientifically necessary.

While society may still be decades from watching a human walk on Mars, research happening today is what will make that possible. The science of space exploration goes beyond rockets and rovers: Contributions and collaboration from a wide range of disciplines are needed, including soil science, crop science, and agronomy.

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Slides, audio, and video from a symposium on this topic at last year’s ASA, CSSA, and SSSA Annual Meeting are available in the ACSESS Digital Library at https://dl.sciencesocieties.org/publications/meetings/2016am/16099.