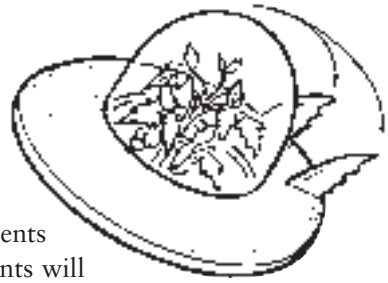
Exploring Plants in Space



Space is the next frontier — full of adventure, challenge, and reward. To ensure that the United States remains at the leading edge of space travel and technology, NASA has laid out these goals as part of its "Vision for Space Exploration":

- Complete the International Space Station and retire the space shuttle by 2010.
- Develop a new transportation vehicle and return to the moon by 2020.
- Continue robotic explorations of Mars and planning for future visits or colonization by humans.

Developing ways to grow plants in space will be part of achieving each of these goals. Although plants may not be the first image to pop into your head when envisioning space travel, leafy green companions will play an important role in future extraterrestrial explorations. Since there are no convenience stores along the way, extended travel in space vehicles or long stays on the International Space Station, the moon (a 4-day trip), or Mars (a 6-month trip) necessitate the ability to grow supplemental food, provide oxygen, and filter water. Without a way for astronauts to be self-sufficient, long journeys or new settlements would be extremely risky. What if the spacecraft carrying replacement supplies was delayed?

Ultimately, scientists hope to design a bioregenerative life-support system containing all the elements needed to sustain life, so that humans and plants can provide for each other's needs in space as they do here on Earth. In the system, oxygen will be produced by plants and consumed by humans, who will then produce carbon dioxide, which will be used by plants. Plants will provide food for humans, and human waste will be broken down by microbes in bioreactors to provide nutrients for plants. Additionally, plants will help to purify water needed by both plants and humans.

Sound simple? It's not. Growing plants in space is not like growing plants on Earth. Water, light, and growing room are limited *and* plants must adapt to life with reduced gravity. To overcome these challenges, botanists, horticulturists, and agricultural engineers are working to create and test growing systems suitable for space travel. These plant-growth chambers control temperature, light, humidity, air quality, air pressure, moisture, and nutrient delivery so that plants can reach maturity in space. And breeders are developing new plant varieties that will better tolerate these challenging conditions.

Exploring Plants in Space helps to cultivate the next generation of scientists and astronauts, who will invent and implement the technology that will allow us to continue our celestial explorations. In order to pursue this technology, students first need a foundation in basic plant biology and botany. The information and lessons in this booklet introduce and reinforce this learning by exploring the benefits and challenges of growing plants "where no plant has gone before!"

Although it would be hard to simulate the growing conditions of the International Space Station, the moon, or Mars in your classroom, the experiments in this guide bring plant biology to life for students and help them better understand the research currently being conducted by scientists.

Important: Throughout this booklet we recommend online resources from NASA and other programs that provide important teacher background information and student readings. You'll find easy-to-use hotlinks to all of

these resources at the Kidsgardening.org Web site (*www.kidsgardening.org/space*). Links are also spelled out on pages 33–34 of this booklet. In both places, the links are organized by lesson, listed in the order they occur, and labeled with a corresponding number to help you locate them easily.

Why We Need Plants in Space

There's no question about it — plants are vital to our very existence. They provide us with food, oxygen, and shelter. But have you ever stopped to think about how these benefits would translate beyond our planet?

Traveling with plants is not a new concept. Early explorers and colonists coming to the Americas frequently packed clippings of and seeds from their favorite green friends. Growing plants from their native lands provided travelers with familiar sources of food and medicine and also helped with another common ailment: homesickness. Plants can provide similar benefits to astronauts.

Food. Currently NASA compares its food system for astronauts to a picnic because space travelers must pack everything they consume. Their meals include few if any fresh fruits and vegetables due to limited room and rapid spoilage. But as we use the International Space Station, and someday have an outpost on the moon and colonies on Mars, we'll need a renewable food source that will be more economical than "packing groceries." Besides, fresh produce provides nutrients, flavor, texture, and variety to meals that break the monotony of packaged foods.

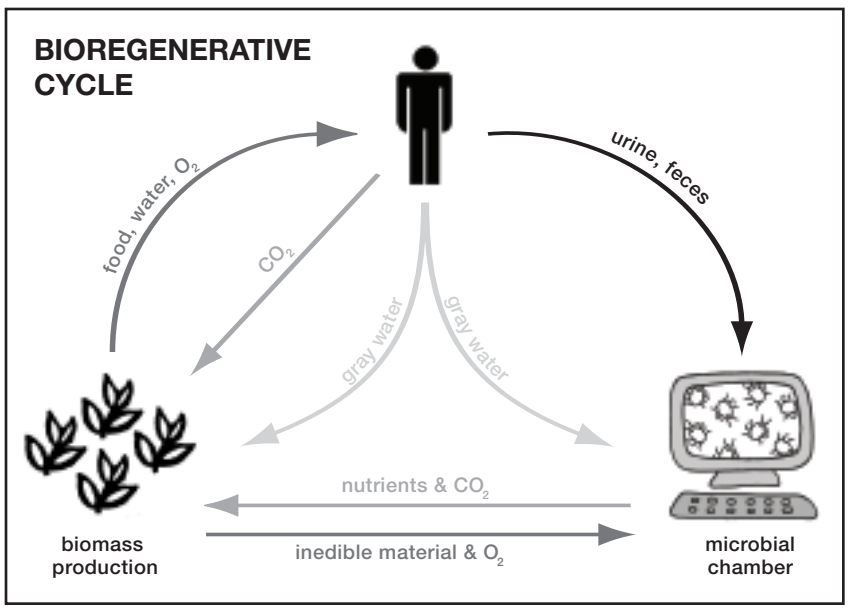
Air. Plants use carbon dioxide (CO_2, produced by astronauts) and produce oxygen (O_2, consumed by astronauts) through the process of photosynthesis. They also remove chemical pollutants from the air. Plants would improve the air quality inside spacecraft.

Water Purification. It costs about $22,000 per kilogram to ship objects into space! This makes water, at about 3 kilograms per gallon, a very expensive commodity, so creating a way to reuse water would be very beneficial. Plants can play a role because they produce pure water in the process of transpiration. Scientists are developing techniques to irrigate plants with wastewater — such as that from washing — and then recapture the purified water given off during transpiration.

Waste Recycling. Scientists are also investigating ways to recycle human waste and inedible plant matter to provide nutrients for plants. This is an important element for creating a self-contained ecosystem.

Lifting Spirits. The psychological benefits of plants are hard to measure, but they're clearly evident. Just as parks and other green spaces help urban dwellers unwind and rejuvenate, astronauts surrounded by metal and plastic within a cramped space benefit greatly from the presence of plants. Horticultural experiments are incorporated into missions not only to advance knowledge and technology, but also to provide astronauts with a little connection to home. While producing food in space is serious work, the act of gardening provides enjoyment, relaxation, and recreation.

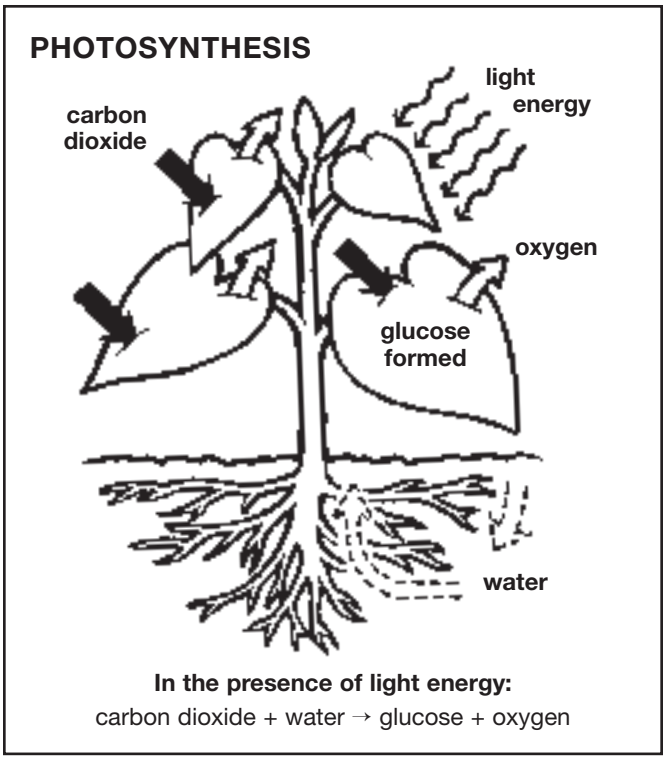
There is no argument among space scientists about the benefits of leafy green "astronauts," but finding efficient and successful ways to grow plants in space is one of their biggest challenges.



Plant Needs

Plants grown in space have the same needs as those grown here on Earth — water, air, light, nutrients, and a place to grow — but finding a way to meet plants' needs in a spacecraft, space station, or lunar or martian environments is very challenging. The reduced gravity, lack of room, and need to keep weight to a minimum mean that space gardens must differ greatly from their earthly counterparts.

Let's talk a bit more about basic plant needs, and the challenges of meeting them in space:



Water: Water is required for photosynthesis (production of food) and transpiration (evaporation of water from leaves into the air, cooling the plant and creating pressure to move water from roots to leaves); it also aids in the absorption of some nutrients.

Challenges: Water is heavy to transport, so astronauts pack only the amount they need for survival. In low gravity, traditional watering is not an option because water droplets bounce off the soil surface. Water must be directly applied to and absorbed by growing media, or incorporated into the media.

Air: Plants take in carbon dioxide (CO_2) and oxygen (O_2) to use during photosynthesis. People provide carbon dioxide through respiration.

Challenges: Air doesn't circulate naturally in space. The oxygen released by plants during photosynthesis can accumulate around them and lead to plant death unless fans keep the air moving. Other gases harmful to plants can also collect inside spacecraft and must be removed.

Light: Plants capture light energy for use in photosynthesis, the process by which plants make food.

Challenge: Spacecraft have few windows, so growing plants requires artificial light. Lights must be energy efficient to avoid overtaxing limited energy resources.

Nutrients: Plants require certain minerals for proper biological function and growth. Nutrients occur naturally in soil on Earth as a byproduct of the decomposition of organic matter or they can be added through applications of fertilizer. (Fertilizer is sometimes referred to as "plant food," but because plants make their own food through the process of photosynthesis, fertilizer should more accurately be compared to a multivitamin.)

Challenge: Lunar and martian ground lacks the nutrients plants need, so nutrients must be brought to these sites. Scientists are investigating ways to recycle waste to provide nutrients for plants.

Growing Media: Plants need somewhere to grow. On Earth, most crops grow in soil.

Challenges: The weight of traditional garden soil and potting mixes makes them impractical in space. Scientists are experimenting with different media such as gels and soilless mixes, along with techniques like hydroponics to devise an acceptable alternative to soil. Additionally, the low-gravity environment changes the way roots, shoots, and water behave in space, so the design of growing containers must help plants overcome the effects of reduced gravity.

Challenges of Gardening in Space

Since plants, like humans, aren't native to space, adaptations must be made to ensure their survival. The chart on page 6 illustrates some of the challenges plants face.

Keeping in mind basic plant needs and the challenges of meeting those needs in space, scientists are working to develop new plant varieties that will grow well in space. They are using three different approaches: (1) creating growing systems to provide acceptable environmental conditions (e.g., plant-growth chambers and greenhouses); (2) selecting specific characteristics from existing plants and using them to breed new varieties better suited to growing in space; and (3) engineering plants that are adapted to the space environment. Ideal space plants:

- are short
- grow in low light
- have few inedible parts
- grow quickly and produce a reliable harvest
- resist disease
- need little water and few nutrients
- need little maintenance
- yield a lot of oxygen

	Vehicles/International Space Station	The Moon	Mars
Limited space	x		
Limited water	x	x	x
Reduced gravity	x	1/6 Earth's gravity	1/3 Earth's gravity
Limited or no air circulation	x	x	x
No pollinators	x	x	x
Little or no atmosphere		x	Less than 1% of Earth's atmosphere
Extreme temperatures		Range: -387°F to 253°F	Range: -207°F to 80°F
High levels of radiation		x	x
Low nutrient content in surface materials		x	x

Although scientists face many challenges as they explore ways to grow plants in space, they must find solutions in order to continue space exploration. Through innovative thinking and persistence, vacations to the moon or colonies on Mars will move from a dream to reality — and your students may become the scientists who help make it happen!