

HYDROPONICS ON THE MOON

by Bruce Bugbee

Since 1981, I've been involved in NASA-sponsored research on growing food plants in a lunar colony. The controlled-environment life-support system (CELSS) is a high-tech system, designed to produce maximum yields. We regulate light, temperature, humidity, airflow and carbon dioxide levels in order to create an optimal environment around the plants' leaves. We use hydroponic culture to provide the optimal levels of water, nutrients and oxygen around the plants' roots.

All kinds of crops, even tubers like potatoes, can be grown hydroponically, but our specialty is growing wheat. We sow the wheat seeds onto $\frac{3}{4}$ -in.-thick layers of moistened rockwool, a sterile, inert, fibrous material that supports the plants. The rockwool mats fit like lids over plastic tubs that hold a recirculating nutrient solution. Each tub is about 16 in. by 20 in. by 4 in. deep, and holds approximately 5 gal. of liquid. If the seeds are grown in very bright light, comparable to full sunlight at noon on a summer day, a single tub can yield as much as 2 lb. of grain—several times more than the highest productivity ever achieved in a wheat field.

I need to emphasize that hydroponics is only part of our system. What's most important in achieving rapid growth and high yields is supplying enough light. I always point this out to hobbyists who ask me how to grow lettuce, tomatoes or other crops hydroponically for their winter salads. Whether the roots are in soil or in nutrient solution, if a plant isn't getting enough light it won't grow or set fruit. In the lab, we use high-pressure sodium lamps, and leave them on 24 hours a day. (Wheat doesn't need or benefit from a dark period.) A lunar farm would have to be built underground for protection from high levels of damaging radiation. For light, it could use fiber optics to pipe in sunlight during the lunar day, or electric lamps. The light needed for maximum plant growth is about one hundred times brighter than what's needed for humans to do their work.

If plants are given enough light, then the density and yield of a crop are often limited by underground competition for water and nutrients. This is where hydroponic culture can make a big difference. The optimal density for wheat plants growing in a field is between 200 and 400 plants per square yard. A CELSS hydroponic garden, however, can support as many as 2,000 to 8,000 plants per square yard. It would be impossible to grow plants at such high density in field soil—the roots wouldn't be able to absorb water and nutrients fast enough. During an approximately 80-day life cycle, the wheat plants in one of our tubs typically take up and transpire more than 50 gal. of water.

The flowing hydroponic solution delivers water and nutrients to the



Author Bugbee sows wheat seeds on a $\frac{3}{4}$ -in. layer of rockwool that fits like a lid over a 16-in. by 20-in. by 4-in.-deep plastic tub filled with recirculating nutrient solution. These 15-day-old plants have already produced a dense mass of fibrous roots. The yellowish light comes from high-pressure sodium lamps that illuminate the crop 24 hours a day.

roots, so they don't have to keep growing in search of new supplies. In fact, we've found that the wheat plants' root systems reach full size within the first 24 days after germination, and that's sufficient to supply the tops of the plants for the rest of their life cycle. By contrast, wheat plants in field soil continue growing new roots until harvest time. Another difference is that most of the water and nutrient uptake occurs close to the tips of the roots in field soil, but in hydroponic culture the absorption can take place at considerable distances (up to 20 in.) behind the root tip.

The CELSS supplies custom nutrient solutions tailored to improve plant growth and yield. It includes carefully measured proportions of the 13 elements essential for plant growth: nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, boron, manganese, zinc, copper, molybdenum and chlorine. During the life cycle, a tub's crop of wheat absorbs about 2½ oz. of mineral elements.

Roots also need oxygen. The best way to supply it is to circulate the solution. Roots quickly absorb all the dissolved oxygen from the water immediately adjacent to them. In stagnant water, the only way more oxygen can reach the

roots is by diffusion, which is a very slow process. But if the water is kept rapidly flowing, the stagnant zone next to the roots is kept very small and the dissolved oxygen reaches the root surface. In our system, the water is aerated when it cascades from the growing tubs down into a storage tank. Then it's pumped back into the tubs at a flow rate of roughly a pint per minute.

We've demonstrated that a lunar hydroponic farm could produce high yields, but the price tag will be astronomical. Transporting material to the moon can cost as much as \$6,000 per pound, which means that an ounce of water on the moon may be more valuable than an ounce of gold on earth. To support ten lunar colonists, a CELSS farm with an area of 360 sq. yd. would need almost 16,000 gal. of water and 440 lb. of mineral salts. Although the water and salts could be recycled, it would all have to be transported to the moon to start with. Of course, this is only a fraction of the mass of equipment and structures that would have to be transported to build a lunar station.

It may be quite a while before a CELSS is put to use on the moon. In the meantime, what we're learning about the factors that affect crop productivity will pay off here on earth. □

Bruce Bugbee teaches crop physiology and hydroponics at Utah State University in Logan, Utah.