Controlled Environment Systems Research at the University of Guelph

By Michael Stasiak

It is clear that future human exploration of space will be based on biological life support systems which utilize plants and microorganisms. Currently, space-mission vehicles are able to carry enough food, water, and air to keep crews alive for short missions. For extended durations, such as on the International Space Station, resupplying life support components is required at regular intervals. During longer space missions at distances in which resupplies are uneconomical or unfeasible, as in a permanent Lunar base or a manned mission to Mars, the needs of the crew can only be met by developing renewable life support systems based on plants and microorganisms. As the primary basis of life on earth, plants are uniquely capable of providing the most efficient means of sustaining life in space. They are able to provide food, potable water (through transpiration) and oxygen, while removing carbon dioxide and helping eliminate polluting by-products and waste.

The NSS Roadmap to Human Settlement of Space, outlined at the 19th International Space Development Conference, defined the lack of a closed loop life support system as one of the 13 barriers to space settlement. In an effort to overcome this barrier, research in the area of biological life support is underway at a number of institutions throughout the world, including the University of Guelph in Canada. Typically, Canadian space research involves Earth observation and communication satellites and robotics like the famous Canadarm. But the only Canadian institution involved in life support research for space is the University of Guelph. Based on terrestrial expertise in sealed environment systems, nutrient recycling, microbial technology and plant physiology, and initiated by the technical achievements that have enabled the Canadian greenhouse industry to readily grow plants in closed environments during the winter, the University of Guelph's Controlled Environment Systems (CES) research has developed into a multi-million-dollar program dedicated to the study of biological life support systems for future space exploration. With partners that include NASA, the European Space Agency and the Canadian Space Agency, the CES laboratory draws together some 70 faculty, staff and students.

The recently completed CES facility houses numerous plant growth systems and a myriad of state-of-the-art analytical equipment. Undergraduate, MSc and PhD students are involved in all aspects of the life support research process, from system engineering and construction to experimental design and implementation. A number of areas of importance to biological life support system design and function are being explored, including: efficient energy supply for dense plant canopies, nutrient cycling and remediation, indoor air quality, selection of candidate plant species, and evaluation of plant growth under conditions of low atmospheric pressure.

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Efficient Energy Supply for Dense Plant Canopies: The amount of real estate available in space for biological life support systems is limited, so methods to grow plants productively in as small a space as possible is an important consideration. In a developing plant canopy, the lower leaves eventually become shaded from above by newer leaves as the plants grow, resulting in a decrease in overall photosynthetic efficiency. The primary purpose of this area of research is to investigate the potential value of adding light to the lower leaves of a dense plant canopy for the purpose of improving photosynthetic efficiency and increasing basic life support requirements for oxygen, water, and removal of carbon dioxide. These experiments utilize two sophisticated closed loop plant growth chambers equipped with numerous atmospheric sensors that provide detailed analysis of temperature, humidity, oxygen and carbon dioxide levels, as well as monitoring other gases and volatile organic compounds. Research to date has shown that by adding light to the lower canopy, increases in net oxygen, water, biomass production and carbon dioxide removal can be achieved.

Controlled Environment Systems chambers.

Nutrient Cycling and Remediation: Since nutrients and water must necessarily be recycled in a closed loop biological life support system, the consequences of closure on ionic balance, microbial activity and plant response are areas of concern. This research is primarily concerned with the quantification of nutrient uptake in re-circulating hydroponics solutions, sensor technology evaluation, and assessment and development of water treatment and water delivery technologies for the management of yield reducing microorganisms and solution borne organic compounds. Some of the specific research areas include the study of the influence of ion accumulation on crop production, investigation of rhizofiltration of sodium from hydroponic solutions, evaluation of ozonation technology as a hydroponic remediation tool, development of methods for early detection of plant responses to Pythium infection, evaluation of individual ion sensors for control strategies in recirculating systems, and management of microorganisms and inorganic nutrients in closed cycle hydroponic systems.

Indoor Air Quality: The quality of indoor air of partially sealed spaces such as urban office buildings represents an obvious extension of research on sealed environments. Sensor technologies similar to those used in closed environment studies have been employed to monitor and evaluate the atmospheric quality typically associated with "sick building syndrome." The scope of activities began with direct measurements of efficacy in the remediation of indoor air using complex ecosystems as biological filters (biofilters). The ecosystems are composed of higher plant species, recirculating aquaria, fish, amphibian and insect species, and the associated microbial flora and fauna. This research is dedicated to the evaluation of the influence of complex plant communities on indoor air quality. Experiments have demonstrated that this type of system can remove substantial levels of airborne pollutants, and studies continue on the influence such an environment on human psychological factors.

Assessment of Candidate Plant Species: Photosynthesis, in the context of life support, can loosely be defined as the consumption of carbon dioxide and the production of oxygen and biomass for food. The capacity for plants to exhibit enhanced photosynthesis at lower light levels has profound implications on the exploitation of plant-based life support in extraterrestrial applications. This research is focused on selection and assessment of candidate plant species which show enhanced levels of photosynthesis, with the principal goal of improved growth and yield of densely planted crops.

Hypobaric (Low Pressure) Plant Growth: The pressure on Mars is less than one percent of what it is on Earth. One of the key questions facing scientists is whether plants could thrive at pressures lower than that on Earth. A prototype variable pressure growth chamber, designed by the CES research team specifically for the study of long-term plant growth under low atmospheric pressures, is currently being evaluated. Within the next two years a total of fourteen hypobaric plant growth chambers will be constructed. They will provide a venue for the study of plant growth and development, photosynthetic gas exchange, air quality, and hydroponic solution remediation technologies under atmospheric conditions common to extraterrestrial exploration and habitation.

Even though consumption of carbon dioxide and production of oxygen, water and biomass for food are the natural consequences of photosynthesis and growth in plant systems, the technical challenge in harnessing these to support human life in a sealed space results mainly from the limited volume and capacity of the system. The technical objectives of the CES research program are designed to give us clearer insight into the evaluation of more complex, stable ecosystems comprised of hundreds of species, which will ultimately form the basis for a self-sustaining life support system with application in space.

Canadian government sponsors of the CES research program include the Canadian Space Agency (CSA), the Centre For Research in Earth & Space Technology (CRESTech), Environment Canada, and the Ontario Ministry of Agriculture, Food & Rural Affairs (OMAFRA). ✯