4th Annual International Space Ecology Workshop

Aug 8-9, 2025
0800-1600 Pacific Daylight Time

Closed System Ecology | Crop Production and Waste Recycling | BLSS and CELSS

The global Space Ecology Workshop is a free, virtual 2-day conference that connects academia and industry to advance the science and art of supporting diverse life in space.

Welcome Space Ecology Professionals!

Welcome to the 4th Annual Space Ecology Workshop, an international forum for discussing the ecological aspects of sustainable space habitation. We believe that there is a need to promote and organize closed ecological and bioregenerative life support (CELSS/BLSS) research internationally and reignite interest in an ecological systems approach to space habitation, especially given the current momentum for deep space exploration. We share a mutual vision of artificial closed loop ecosystems that exploit a combination of biological, ecological, and electromechanical processes to support human life.

Closed ecological systems will enable indefinite, sustainable human exploration of space as well as sustainable living on Earth. Many prior needs assessments point out similar gaps in knowledge and technology, and many obstacles remain in realizing this vision. We believe that advances will be made when we coordinate efforts and socialize these concepts globally. We hope this workshop can provide inspiraΘon and momentum to that end, and that there will be many more. We are so glad you've joined us!

Major Themes Include:

Enabling a Sustainable Presence in Space: Maintaining a permanent presence in space is untenable without a degree of self-sufficiency. We discuss technologies that contribute to mission longevity by enhancing crew health, closing material or energy loops, and replacing or reimagining physio-chemical life support systems.

Closed Ecological Systems for Deep Space: The understanding and development of artificial ecosystems are critical to achieve long term goals in life support and physical and mental health needs for crew. A major goal of this workshop is to coalesce research on closed ecological systems: highlight applicable existing research, identify gaps in knowledge, and coordinate future high-priority research.

Crop Production and Waste Recycling: Closing the material loop in food production and waste recycling systems is necessary to reduce reliance on regular resupplies. Extensive space agriculture will be a prerequisite for space habitats with permanent residents. Topics of interest include: improving yield, designing with automation, crop cultivar selection, and water and nutrient delivery systems.

2025 Space Ecology Workshop Agenda

Day 1, August 8, 2025. All times in Pacific Daylight Time (PDT)

8:00 - 8:15am	**Opening Remarks** Patrick Grove, The Spring Institute for Forests on the Moon
8:15 - 9:00am	**Featured Speaker** Christine Chamberlain, Space Lab Tech: *Artemis LEAF Mission Update*
9:00 - 10:00am	**Morning Presentations** Jacob Scoccimera, Monolith LLC: *Aquaculture Systems for Microgravity* Borja Barbero, Texas A&M / Moon Village Association: *Germinating Resilience: Telomere Biology in the Space Environment*
10:00 - 10:30am	**Coffee Break & Breakout Room Discussion**
10:30 - 12:00pm	**Morning Presentations, Continued** Chip Small, University of St. Thomas: *Nutrient recycling from compost-based urban agriculture--Applications for space habitats* Ahsan Nasir, University of Clermont Auvergne: *Challenges in Simulating Constructed Wetlands for Space: Gravity and Lunar Regolith as a Design Constraint in the Contaminant Removal Optimization* Livian Von Dran, The Spring Institute for Forests on the Moon: *The Semantics of Space Ecology*
12:00 - 1:00pm	**Lunch Break & Breakout Room Discussion**
1:00 - 1:45pm	**Featured Speaker** Lisa Carnell, NASA Biological and Physical Sciences: *Science to Enable Sustainable Habits Off-Earth*
1:45 - 2:45pm	**Afternoon Presentations** Shriya Musuku: *Closed-Loop Life Support Systems for Long-Duration Spaceflight: Current Capabilities and Future Directions* Donald Coon, University of Florida: *Sensitivity and Evaluation of the Energy Cascade Models Biomass and Transpiration Predictions for Controlled Environment Plant Production*
2:45 - 3:00pm	**Coffee Break**
3:00 - 4:00pm	**Afternoon Presentations, Continued** Harrison Coker, Texas A&M: *Aeroponic Technology for Accelerated*

	Weathering of Extraterrestrial Regolith to Extract Plant Essential Nutrients and Generate Arable Soils Bryce Meyer, National Space Society: *Artificial Intelligence and Networks for small settlements*
4:00 - 4:01pm	**Closing Remarks** Patrick Grove, The Spring Institute for Forests on the Moon

2025 Space Ecology Workshop Agenda

Day 2, August 9, 2025. All times in Pacific Daylight Time (PDT)

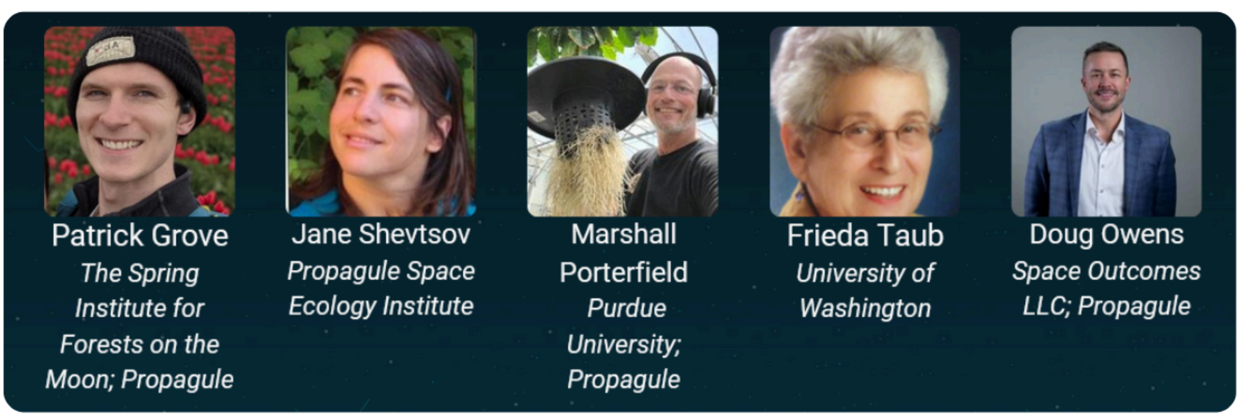
8:00 - 8:15am	**Opening Remarks** Patrick Grove, The Spring Institute for Forests on the Moon
8:15 - 9:00am	**Featured Speaker** Chris Yi Yuan, UMIC Space Habitat: *Talk Title TBD*
9:00 - 10am	**Morning Presentations** Lucia White, US Space Force / US Air Force Academy: *Microgravity Meets the Classroom: Advancing STEM Education and Space Research through the USAFA Parabolic Flight Program* Carla Ruiz-Gonzalez, University of Edinburgh / Scottish Association for Marine Science: *Snow algal plasticity and metabolic responses during a simulated Lunar light cycle*
10:00 - 10:30am	**Coffee Break & Breakout Room Discussion**
10:30 - 12:00pm	**Morning Presentations, Continued** Rachel Rivero, University of Michigan / Moon Village Association / OSDR Plant AWG: *From Soil to Cell: Addressing Nutrient Deficiency and Toxicity in Space Crop Systems* James Ebeling, University of Alabama Huntsville: *Two demonstration growout systems for off-world production of nutritionally rich crops to supplement resupplied staples* Luke Fountain, NASA KSC*: Plants prefer ammonium as a N source: Implications for space crop production.*
12:00 - 1:00pm	**Lunch Break & Breakout Room Discussion**
1:00 - 1:45pm	**Featured Speaker** Kai Staats, Director of Research for SAM at Biosphere 2: *From Earth to Mars (and back to Earth again) - How we will live on Mars tomorrow is how we should be living on Earth today.*
1:45 - 2:45pm	**Afternoon Presentations** Colin Lennox & Briar Fisk, Arcology Solutions: Gaia OS: *A machine learning based operating system for running integrated biological life support and in-situ regolith benefaction systems for colony growth.* Aenghus Denvir, Texas A&M: *Transforming Regolith into Soil: Interactions of Planetary Surface Materials with Organic Amendments*

2:45 - 3:00pm	**Coffee Break**
3:00 - 3:45pm	**Panel - *Funding Space Biology in the Current Climate*** Marshall Porterfield, Zaheer Ali, Jeff Smith, Danica Vallone, Kai Staats, Patrick Grove (Moderator)
3:45 - 4:00pm	**Closing Remarks** Patrick Grove, The Spring Institute for Forests on the Moon

Tips and FAQs

- **Communicating with Speakers and Organizers**: Given the number of attendees, microphones are muted and videos are off by default. However, there are several other ways to communicate with the speakers and with one another:
    - **Zoom Q&A Box for Questions to Speakers**: If you have a question you would like to ask one of the speakers, please enter your questions into the "Q&A" box in Zoom.
    - **Zoom Chat for Comments and Feedback**: Please provide any comments or feedback that you would like to share with the group (other than questions for our speakers), in the Zoom "Chat" box.
- **Will the Workshop be recorded and available to watch later?**
    - **Yes!** The recordings of both days of the workshop (as well as previous years' workshops) will be available on YouTube here:
        - https://www.youtube.com/@spaceecologyworkshop8066
    - Transcripts of the Zoom chat log will also be uploaded to the website after the event (www.spaceecologyworkshop.com)
- **Technical Difficulties**: If you are having trouble accessing anything or have any other technical questions, please message Patrick Grove in Zoom chat. He's there to help!

2025 SEW Organizing Committee



Presentation Abstracts:

- James Ebeling, University of Alabama Huntsville: **Two demonstration growout systems for off-world production of nutritionally rich crops to supplement resupplied staples**
  - *The most practical scenario for food production on off-world sites (Moon & Mars), incorporate the continuous resupply of long storage-life staple crops and the on-site production of additional nutritionally rich vegetables, leafy greens, fruiting and medicinal crops. Together, high-density, long storage-life staples supplemented with fresh, edible crops will provide necessary nutrients, while also enhancing dietary variety. Anecdotal evidence also supports the psychological benefits for astronauts of growing crops, rooted in the enjoyment of eating and caring for plants. Thus, the need not to forget the numerous herbs and spices, leafy greens, and fruiting crops that with the proper chef make any meal into a 'five-star 'experience. Two different types of growout modules have been constructed by students at the University of Alabama Huntsville research greenhouses designed to operate as flow through media bed. The first is a traditional media bed (2 @ 3 ft X 6 ft) and the second, five vertical tower systems (2 beds each) reflecting what NASA has pictured for a Mars colony. Using these two systems, a wide variety of research is being conducted on multiple crops looking at the best crops to grow, how to maximize productivity per volume, what environmental parameters are most important, what crops can be grown together and other growout issues. In addition, this research project has been recognized with a small grant from the Alabama Space Grant Consortium. Finally, design and construction details will be available via social media and web pages to help encourage and support school STEM Projects.*
- Jacob Scoccimerra, Monolith LLC: Monolith Blue: **Aquaculture Systems for Microgravity**
  - *Monolith Blue will be developing a new aquaculture research facility for marine biology and aquaculture research in LEO. There has not been a dedicated facility for this type of research since 2012 with the JAXA AQH. This facility will provide new insights into marine biology in microgravity and will benefit BLiSS and food production for beyond LEO exploration.*
- Borja Barbero, Texas A&M / Moon Village Association: **Germinating Resilience: Telomere Biology in the Space Environment**
  - *Plants have evolved sophisticated regulatory mechanisms to protect their DNA from the ultraviolet radiation necessary for photosynthesis. However, in the unique space radiation environment, these systems face new challenges in maintaining genome integrity. Telomeres, the G-T rich sequences at chromosome ends, are particularly vulnerable to oxidative damage. During the APEX-07 mission aboard the ISS, plants exhibited increased genomic oxidation and a striking 150-fold rise in telomerase activity, suggesting a potential non-canonical role for telomerase in the space radiation response.To investigate this further, we exposed Arabidopsis lines with altered telomerase (TERT) and reactive oxygen species (ROS) scavenging capacity (CAT2) to acute Galactic Cosmic Ray simulations (GCRsim) and to prolonged, low-dose exposures of gamma rays and neutrons. Plants deficient in ROS scavenging or telomerase activity accumulated significantly higher levels of 8-oxoG, a marker of DNA oxidation, while overexpression of CAT2 or telomerase reduced 8-oxoG accumulation under chronic radiation. Oxidative damage was consistently more pronounced under low-dose, long-duration exposures compared to acute radiation.Interestingly, GCRsim exposure elevated genomic oxidation*

    without altering telomerase activity. In contrast, low-dose rate exposures from germination through early development triggered increased telomerase activity, indicating a dose-rate dependent regulatory mechanism. This response was observed in both wild-type and ROS-deficient mutants under chronic γ-radiation at 7.8 mGy/day. Telomerase-deficient plants showed the highest oxidative damage, whereas overexpressors maintained wild-type oxidation levels.These findings implicate telomerase as a dynamic responder to radiation-induced oxidative stress, beyond its canonical telomere maintenance function. Upcoming experiments aboard the ISS as part of the APEX-12 mission will further examine this relationship, using genetically modified lines to deepen our understanding of telomerase regulation under space-relevant radiation conditions. Together, these studies aim to establish an integrated model of telomerase function in plant genome protection during spaceflight.

- Chip Small, University of St. Thomas: **Nutrient recycling from compost-based urban agriculture – Applications for space habitats**
    - *Isolated space habitats require recycling efficiencies of nearly 100% to ensure nutrient availability for crop production. Cities, by contrast, are highly open ecosystems, but efforts to enhance nutrient recycling in urban systems may provide lessons for space habitat design. Our lab has conducted an 8-year study of nutrient recycling and loss from compost-amdended urban agriculture. Stoichiometric constraints result in over-application of phosphorus if compost is added to meet crop nutrient demand. Excess P is predominantly stored in soil, but some P is exported in leachate or runoff. Targeted compost applications achieved P recycling efficiency of up to 89% over the study period. We have used the stoichiometrically-coupled model of water, carbon, nitrogen, and phosphorus, developed for this project to examine how ecosystem services from urban agriculture will be altered under climate change scenarios. This same model could be adapted for closed-system space habitats.*
- Ahsan Nasir, Universite Clermont-Auvergne/The Spring Institute for Forests on the Moon: **Challenges in Simulating Constructed Wetlands for Space: Gravity and Lunar Regolith as a Design Constraint in the Contaminant Removal Optimization**
    - *Constructed wetlands (CWs), known for their passive treatment of wastewater on Earth, offer a unique opportunity to serve dual roles in space: as water recycling systems and as psychologically restorative green spaces. However, their functionality and form must be reimagined in light of two primary constraints, reduced gravity and the use of in-situ materials such as lunar dust. Simulations assessed the effects of gravity, substrate type, and feeding strategy on the removal of contaminants such as organic matter. An optimized intermittent feeding strategy with extended resting periods (10-day downtime) enabled the lunar regolith system to achieve up to 95% COD removal. Comparative analysis revealed that sand outperforms lunar regolith simulant in continuous feeding scenarios but accumulates more inert sludge. The findings suggest that substrate selection, hydraulic properties, and feeding strategy are more critical than gravity alone in determining treatment success. The study provides recommendations for using lunar resources to build and operate a VFCW to treat the waste from a 4-astronaut base and offers insights for minimizing the footprint of CW installations on Earth. In addition to their technical value, such biologically active, plant-integrated systems may be a first step to contribute positively to the astronaut's a sense of connection to nature in confined environments.*

- Rachel Rivero, University of Michigan: **From Soil to Cell: Addressing Nutrient Deficiency and Toxicity in Space Crop Systems**
    - *Space agriculture is essential for sustaining human life during prolonged missions, yet the extraterrestrial environment poses significant challenges to crop nutrition, soil safety, and astronaut health. This study evaluates the nutritional quality and safety of crops cultivated both in Low Earth Orbit (LEO) and on lunar regolith simulants, identifying deficiencies in key minerals such as calcium and magnesium, alongside variable antioxidant profiles. We document the physiological impacts of spaceflight–induced nutrient shortfalls—including altered genetic expression in Ca-regulated bone pathways—and assess the emerging incidence of gastrointestinal dysfunction, notably increased intestinal permeability ("leaky gut"), which impairs nutrient uptake and immune homeostasis. Furthermore, our analysis of plant growth on lunar regolith simulants highlights risks of heavy-metal uptake (e.g., aluminum, chromium) and subsequent toxicity to astronauts. To mitigate these compounded risks, we propose integrated strategies: bioengineering of nutrient-dense, metal-tolerant crops; biofortification approaches to bolster mineral content; incorporation of high-antioxidant species to support oxidative stress resilience; and pharmacogenomic–guided supplementation for individualized astronaut nutrition. By uniting insights from plant stress physiology, genetic regulation, and sustainable extraterrestrial agriculture, this work advances practical solutions for nourishing and protecting crews on deep-space voyages and future lunar or Martian outposts.*
- Shriya Musuku: C**losed-Loop Life Support Systems for Long-Duration Spaceflight: Current Capabilities and Future Directions**
    - *As humanity prepares for extended missions beyond low Earth orbit, the development and optimization of closed-loop life support systems (CLSS) is critical to sustaining human life in space. This presentation provides a comparative analysis of current CLSS architectures across international programs, highlighting the technologies used for air revitalization, water recovery, waste management, and biological integration. Emphasis will be placed on how these systems are evolving to support the physiological and psychological needs of crews during long-duration missions. Gaps and limitations in current designs will be explored, particularly regarding energy efficiency, adaptability, and integration with human health monitoring technologies. The discussion will conclude with an outlook on the future of CLSS approaches that may extend mission longevity and autonomy. By aligning environmental control with human ecophysiology, CLSS can play a foundational role in the sustainability and resilience of future space habitats.*
- Donald Coon, University of Florida: **Sensitivity and Evaluation of the Energy Cascade Models Biomass and Transpiration Predictions for Controlled Environment Plant Production**
    - *Global food demand is projected to increase by 8.5% per capita from 2050 to 2100. Controlled Environment Agriculture (CEA), including greenhouses and Plant Factories with Artificial Lighting (PFAL), offers a promising solution to bridge the production gap and mitigate losses due to climatic uncertainties. The Energy Cascade (EC) family of crop models developed to predict the biomass yield, gas exchange and transpiration of CEA and bioregenerative life support systems (BLSS), however they lack comprehensive evaluation despite 30 years of history. This research investigates the EC versions through a Global Sensitivity and Uncertainty Analysis alongside data from growth chamber production of lettuce.*

The models are highly sensitive to inputs pertaining to light and CO_2 levels and consumption accounting for over half of the sensitivity of outputs while interactions between inputs account for a third or less of model sensitivity depending on the model version and output. The models in general were found to overestimate biomass production and underestimate transpiration rates with RMSE's ranging between 49.58 - 96.99 g m^{-2} and 0.80 – 2.30 L m^{-2} day^{-1} respectively depending on model version. The simplicity and explanatory nature of the EC models make them valuable tools for system design, crop scheduling, resource management and potential educational resources. This comprehensive analysis highlights the impact of methodological changes throughout development of the EC(s) highlighting the need for further parameterization and evaluation while providing a baseline for future development to improve upon.

- Luke Fountain, NASA Kennedy Space Center: **Plants prefer ammonium as a N source: Implications for space crop production**
    - *Long-duration exploration missions will require a sustainable supply of food to support human crews. The spaceflight environment contains high concentrations of CO_2 due to release by astronauts that cannot be completely scrubbed. It is therefore crucial to understand plant responses to elevated CO_2 (eCO_2) environments. Nitrogen (N) is crucial for plant survival, though the effects of eCO_2 on plant N uptake remain poorly understood. Shoot nitrate reduction may be reduced at eCO_2, due to reduced reductant availability for nitrate reduction due to reduced photorespiration and increased carbon fixation. Relative growth rate may be reduced at eCO_2 when N is provided only as nitrate and can be unaffected when N is supplied as ammonium, suggesting eCO_2 may drive increased plant 'preference' for ammonium. However, changes in N preference in response to eCO_2 have, to our knowledge, not yet been studied. In this study, novel stable isotope approaches were used in conjunction with hydroponics and isotope ratio mass spectrometry to determine the effect of space station-like eCO_2 (3000 ppm) on preference for ammonium or nitrate in several lettuce varieties previously grown in space, when both N forms are provided equally. All varieties displayed significant ammonium preference irrespective of CO_2 concentration, however the extent of this preference varied, driven by cultivar differences in size and total N content. Increased ammonium preference was observed for all varieties at eCO_2 compared to ambient CO_2 (410 ppm), driven by increases in nitrogen uptake which plants disproportionately took up as ammonium. These results suggest that future nutrient formulations should favor ammonium as a major N source for space crop production. Moreover, increased ammonium preference may play a role in future plant-based bioregenerative life support systems with higher ammonium concentrations due to waste recycling. Additionally, this research furthers our understanding of plant responses to future high CO_2 climates, allowing the development of future-proof crops to maintain food security.*
- Colin Lennox & Briar Fisk, Arcology Solutions: **Gaia OS: A machine learning based operating system for running integrated biological life support and in-situ regolith benefaction systems for colony growth**.
    - *Gaia OS: A machine learning based operating system for running integrated biological life support and in-situ regolith benefaction systems for colony growth. The Gaia OS (machine learning operating system, OS) and self organizing wetland bioreactors (sowbs) facilitate the efficient addition and cycling of hab waste products with exogenous regolith inputs for colony growth. The OS makes possible*

the stable ecology expressed by the sowbs, habs, and native inputs. The OS treats the biological life support system (BLSS) and/or biological in-situ resource utilization (BISRU) components it is controlling as a black box. The OS sees the sensors, actuators, and goal states set by the user as an unlabeled I/O panel with afferent/efferent sub-sections. Afferent only ever read (the sensors), the efferent are outputs (the actuators). During each sampling the OS reads all sensor and actuator states as input. If there is a positive pressure/feedback that deviates from a desired steady state, it generates a prediction and infers what corrective actions are needed (negative feedbacks) to bring the system trajectory back towards the goal state (homeostasis/steady state). It then outputs those selected actions to the efferent actuators through the efferent output side of the I/O panel. The OS is self learning and can also be trained on preexisting data sets. In this way, if a novel input or condition is sensed, the OS can determine its own course as it is the expert of its own unique ecology. This is necessary considering the complexity and depth of the combined colonies cycling, so that "butterflies" (small, easy to handle issues) don't create "hurricanes" (systemic failure). Considering a BLSS, afferent sensors could be any sensor for water, atmosphere, camera, or other sensor that has a digital output the OS can interact with. Efferent actuators could be all sorts of components related to the BLSS/BISRU ecology. Examples are thermocouples, pumps, bubblers, dosers, vents, compressors… The ultimate use case for this software is to allow for exponential growth of a sowb centered biological life support and regolith incorporation systems through the same natural biotic and abiotic interfaces found on Terra.

- Aenghus Denvir, Texas A&M: **Transforming Regolith into Soil: Interactions of Planetary Surface Materials with Organic Amendments**
    - *The in-situ utilization of Martian and lunar regolith as growth substrates for plants will be a key component of off-world colonies. The use of plant tissue waste as a soil amendment is a meaningful, albeit imperfect, way to transform regolith into a soil capable of supporting life. Additions of plant material, along with a 3-month incubation, increased the nutrient cycling capabilities of both JSC-1A lunar regolith simulant and JSC-Mars-1 Martian regolith simulant and also increased numerous soil health indicators. The cotton plant residue generally provided higher nutrient availability and cycling capacity than corn or mixed plant residue due to quicker decomposition and lower C:N ratio. Nonetheless, plant waste additions were not able to alleviate high alkaline pH in either substrate and, in fact, contributed to soil pH buffering and increased Ti availability in JSC-1A. Plants grown in amended regolith performed less well physiologically compared to their pure regolith counterparts. Future work is needed to be done on maximizing the benefits of utilizing plant waste tissue as an amendment while mitigating the negative impacts.*
- Harrison Coker, Texas A&M: **Aeroponic Technology for Accelerated Weathering of Extraterrestrial Regolith to Extract Plant Essential Nutrients and Generate Arable Soils**
    - *Advancements in off-world food and fiber production should seek to utilize regolith as a source of nutrients and prepare it for use as a solid plant growth substrate. Towards this goal, aeroponic biowaste streams containing both inorganic nutrients and root system efflux from plants provide an opportunity for accelerated weathering and enhancement of extraterrestrial soils. To test this hypothesis, an aeroponic system was built that contained Martian simulant (Mars Mojave Simulant-2; MMS-2), inert sand, and a no-filter control to evaluate the in-line filters*

for simultaneous mineral weathering and recycling of biowastes from wheat. The growth performance of wheat in aeroponics was highly productive across all treatments. After inundation with biowastes from the aeroponic system growing wheat for 40 days, MMS-2 sorbed P and K and released Al, B, Ca, Fe, Mn, Na, and S into the nutrient solution. Generated plant biowaste was mixed into MMS-2 and sand treatments, which increased the extractable Fe, K, Mg, P, and S in MMS-2. Substrate chemical properties were quantified (e.g., total C and N, total and extractable elements, pH, EC, particle size, and P species). Augmentation of MMS-2 with aeroponic biowastes followed by amendment with plant residue greatly improved wheat growth compared with the unmodified MMS-2, which resulted in plant death. This technology expands lunar/Martian base agriculture by offering a means to acquire nutrients from weathered regolith while simultaneously improving the fertility of extraterrestrial soils.

- Bryce Meyer, St Louis Space Frontier: **Artificial Intelligence and Networks for small settlements**
    - *Smaller settlements will be limited in personnel and resources, but will have to grow and manage farm crops for food, networks to manage mission elements, and recycle materials. These problems imply a complex network and hierarchy of systems married to sensor and control networks, data management, and information processing ata scale that may require response nearby (similar to SCADA) but more diverse data sets and the need for some actions to be prioritized over others. This presentation will cover the hierarchy of AI and networks, how AI systems (of the various types) link together to synthesize reasons, and a use case that walks through scenarios.*
- Carla Ruiz-Gonzalez, The University of Edinburgh and The Scottish Association for Marine Science: **Snow algal plasticity and metabolic responses during a simulated Lunar light cycle**
    - *Snow algae are a group of photosynthetic extremophiles that thrive in extreme environments such as Antarctica. Some species belonging to this group can bloom under specific conditions such as high light irradiance, low nutrient availability, and during snowmelt periods (freeze-thaw cycles). These psychrophiles poses remarkable plasticity, remaining dormant in a cyst stage when conditions are unfavourable, and accumulating high value compounds such as carotenoids. The same adaptations and metabolites that give these organisms their distinctive profile might also allow them to grow on space stations and in Lunar or Martian conditions. Their ability to photosynthesize nutritious biomass whilst consuming carbon dioxide and generating oxygen make them ideal candidates for supporting extra-terrestrial human exploration. With longer-term missions, new developments like Biological Control and Life Support Systems (BCLSS)- simplistically representing a closed loop involving microalgae as the main component to provide oxygen, food, and medicine to the crew- are being investigated. To date, only model species belonging mainly to Chlorella, Chlamydomonas and Limnospira genera have been investigated for space biotechnological applications, but less research has been done using extremophilic species. An important aspect being considered for applying microalgae in space research are their long-term cultivation stability in xenic (non-axenic) or axenic conditions. Axenic cultures are completely free of any living organisms except for the microorganisms intentionally introduced in the culture whereas xenic cultures could contain a consortium of microorganisms. Maintaining axenic cultures for long-term periods is challenging and would require*

complex procedures in space. However, xenic cultures could be necessary for some algal species to prosper, as mutualistic interactions with bacteria and fungi have been reported for some species. Even so, xenic cultures are also susceptible to suffering bacterial blooms and pathogens that can be harmful to humans. In this study we investigate whether two snow algae isolates, a psychrophilic isolate Limnomonas sp 9-1A and a psychrotolerant isolate Chloromonas sp 34-1A could successfully adapt to a lunar cycle (~14 Earth days darkness: 14 Earth days light) to gain insight into their potential cultivation in a Moon base station. We also investigate the growth performance of the two isolates during the simulated lunar cycle cultured in axenic and xenic conditions to answer the following: Do axenic isolates grow best than the xenic isolates? Are axenic isolates susceptible to being contaminated by other organisms? Do xenic cultures get outcompeted by other cell types? Furthermore, we analysed the key metabolic shifts during the simulated lunar cycle and xenic and axenic conditions to elucidate their physiological adaptative strategies and understand which culturing conditions are more feasible to prosper in space.

- Lucia White, US Air Force Academy Dean of Faculty / US Space Force: **Microgravity Meets the Classroom: Advancing STEM Education and Space Research through the USAFA Parabolic Flight Program**
    - *The United States Air Force Academy's (USAFA) parabolic flight program provides cadets with a unique, hands-on opportunity to design, test, and fly experiments in a microgravity environment. Embedded within the US Space Force's Azimuth program and supported through a $13M initiative (12 flights in FY25), this multidisciplinary effort bridges operational relevance, scientific inquiry, and cadet development. Each summer, select cadets collaborate with faculty, military partners, and external research institutions to prepare and launch experiments aboard commercial parabolic flight campaigns. Projects span diverse domains including human performance, fluid dynamics, biotechnology, and space systems engineering. The program also integrates payload development in coordination with the DoD Space Test Program, giving cadets real-world exposure to the constraints of spaceflight readiness and mission timelines.*

      Now in its fourth year, the program has flown dozens of cadet-led investigations and trained future Guardians in the challenges of experimental design, data collection, and teamwork under dynamic flight conditions. This presentation will outline the program's structure, outcomes, and lessons learned—demonstrating how USAFA's model can serve as a blueprint for combining undergraduate education with meaningful contributions to national space science and technology goals.
- Livian Von Dran, The Spring Institute for Forests on the Moon: **The Semantics of Space Ecology**
    - *As interest in off-world colonization grows, research supporting the development of self-sustaining colonies grows more relevant. Planets subject to colonization are unlikely to be hospitable to humans, necessitating closed environments not reliant on outside matter exchange. In such isolated environments, established ecosystems are needed to mimic Earth conditions and supply resources to the environment's occupants. Despite the essential role ecosystems will play in space habitats, space ecology remains a neglected field of study. To define space ecology and explore its relevance to space exploration and closed ecological life support*

systems (CELSS), a comprehensive literature review will be conducted to establish its historical context and construct a hierarchical framework sequentially examining space biology, ecosystems, and bioastronautics. A competitive landscape diagram will be created to identify representative institutions relevant to examined terms. This analysis will conclude with a critical examination of the research and policy implications of space ecology, highlighting existing gaps and obstacles in its research and development landscape.

- *Some presenters did not submit abstracts and were thus omitted from this list.*