TYPE Editorial
PUBLISHED 08 March 2024
DOI 10.3389/fspas.2024.1394073

OPEN ACCESS

EDITED AND REVIEWED BY
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RECEIVED 29 February 2024
ACCEPTED 04 March 2024
PUBLISHED 08 March 2024

CITATION
Izzo LG, de Vera J-PP and Verseux C (2024), Editorial: Presentations at the 2022 MELiSSA conference—current and future ways to closed life support systems. *Front. Astron. Space Sci.* 11:1394073. doi: 10.3389/fspas.2024.1394073

Editorial: Presentations at the 2022 MELiSSA conference—current and future ways to closed life support systems

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KEYWORDS

bioregenerative life support systems (BLSSs), micro-ecological life support system alternative (MELiSSA), long-term crewed missions, food production and waste management, air revitalization, modelling and control, circular economy, terrestrial applications

Editorial on the Research Topic
Presentations at the 2022 MELiSSA conference—current and future ways to closed life support systems

Long-duration crewed missions, as foreseen to the Moon and Mars, will require sustainable life support systems. Some functions, such as carbon cycling, will require biology. In 1989, ESA's MELiSSA project was consequently initiated to generate knowledge on bioregenerative life support systems (BLSSs). At the core of this project was a concept where a loop of processes produce food, water, oxygen, and other resources while recycling waste. Over the following three decades, the MELiSSA community have used a progressive approach to refine, characterize, model, and control that loop. Beside laying the foundation for a system that could support long-term crewed missions, this undertaking has led to sustainable applications on Earth.

At the 2022 edition of the MELiSSA Conference (held in Toulouse, France), experts discussed recent achievements and future directions in BLSSs with a focus on circular economy–for space and Earth. Participants were invited to report on their key findings in the present Research Topic. Here we give an overview of the published contributions.

Among the central functions of BLSSs are air revitalization and food production. Both can be performed by photosynthetic organisms. Most often, these are plants; consistently, four contributions were about them. Schiefloe et al. investigated the possibility of using waste streams, including human urine, as fertilizer. They cultivated lettuce with various NH_4^+-to-total N ratios, as well as elevated concentrations of Na^+ and Cl^-, and obtained result which underline the importance of nutrient solution composition, particularly the ratio of ammonium to nitrate, when optimizing biomass production.

Kitaya et al. investigated the effects of fish density on the productivity of lettuce plants and loach fish, as well as on nitrogen usage efficiency, in an aquaponic system. They also showed that plant growth was not affected when replacing a fraction of the fertilizer with loach excreta, suggesting that the latter could be used to supplement chemical fertilizers.

Plant production requires seeds; and the transportation of large amounts of seeds from Earth would harm the sustainability of long-duration missions. Iovane et al. consequently studied the capacity of plants to reproduce beyond Earth. More specifically, they tested the effects of microgravity (simulated using a clinostat) on the directional growth of pollen tubes in *Solanum lycopersicum* and *Brassica rapa*. They observed significant changes in the growth patterns, tube length and tortuosity of pollen tubes, as well as in pollen germination.

Supplementing the astronauts' diet with bioactive compounds may help them cope with stress and, more broadly, increase their physical and mental health. The cultivation of microgreens in space is therefore the subject of increasing focus. Amitrano et al. investigated the importance of optimizing environmental factors, such as light intensity and vapor pressure deficit, to enhance their growth and nutritional properties. They also emphasized the potential microgreens have for food production in space habitats, underlining their suitability for cultivation in limited volumes, and suggest that species-specific cultivation strategies may help improve growth and nutritional benefits.

Plants are not the only photosynthetic organisms under study in BLSSs: others are microorganisms. The MELiSSA loop, for instance, includes the cyanobacterium *Limnospira indica*. Two studies in the Research Topic deal with this organism. Tallec et al. addressed the need for an automated process for harvesting its biomass and recycling its culture medium. They developed the BioHarvest demonstration unit, which consists of three subsystems: a photobioreactor, a biomass harvesting unit (BHU) and a medium filtration unit based. Despite biomass accumulation on the filter of the BHU, which can limit productivity, their results are promising. Fahrion et al. aimed at optimizing culture conditions for the propagation of *Limnospira indica* in space. They reported that, among various tested combinations, rather low light intensities (36–80 μmol photons m^{-2} s^{-1}) combined with moderate temperatures (30°C–34°C) were most favorable in terms of biomass production and pigment composition. Perozeni et al. demonstrated the successful heterologous expression of zeolin–a recombinant protein with a balanced amino acid profile–in another photosynthetic microorganism: the eukaryotic microalgae *Chlamydomonas reinhardtii*. This achievement may be a step toward microalgae which are metabolically engineered to better meet the crew's dietary requirements.

Not all microorganisms of relevance to life support are confined to dedicated compartments. Doré and Ortega Ugalde highlighted the impact–positive or negative–the microbiome can have on health and emphasize the benefits that its understanding can bring, not only for medical applications but also for enhancing the sustainability of life support systems. They also pointed out the limited number of studies, as well as their sample size and diversity, which have focused on astronauts' microbiome. Another concern pertaining to microbiomes is the contamination of crewed compartments. Lemelle et al. presented insights from the MATISS campaigns, in which the surface contamination rates of the Columbus module, in the International Space Station, were documented over months. They revealed low levels of biocontamination, which they attributed to the effectiveness of long-term air purification systems, and suggested that surface contamination is roughly proportional to the number of astronauts.

When designing BLSSs, creating individual compartments is only one of the challenges. Another is their integration. A stoichiometric model proposed by Vermeulen et al. offers a framework for analyzing nutrient cycling and resource utilization in a conceptually closed, MELiSSA-inspired BLSSs. The authors described a remarkable level of closure–with 12 out of the 14 included compounds showing zero losses, and the continuous provision of 100% of the food and oxygen needs–when balancing the scale of the different compartments.

Overall, the presentations at the 2022 MELiSSA Conference–only a small fraction of which led to articles in this Research Topic–showed that researchers of the MELiSSA community are making significant steps towards sustainable life support systems–as well as inspiring and developing terrestrial applications.

Author contributions

LI: Conceptualization, Writing–original draft, Writing–review and editing. J-PdV: Conceptualization, Writing–review and editing. CV: Conceptualization, Writing–review and editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

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