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HIGHER PLANTS IN CLOSED LIFE SUPPORT SYSTEMS

- REQUIREMENTS FOR FUTURE RESEARCH

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Future long term mission to the Moon and Mars rely on a life support system capable of regenerating all the essentials for survival. As identified through MELiSSA (Micro-Ecological Life Support System Alternative), such regenerative life support systems need to include a compartment for production of higher plants. Plants provide a regenerative food source, aid in oxygen production, and contribute to purification of air and water.

In general, the available information regarding effects of the space environment on plants is inconclusive, and suffers from limitations in available flight hardware, sensor technology and research facilities that simulate space conditions. In addition, more work is necessary on the canopy scale and with food crops relevant for life support. On the whole, the available literature seems to prove that plants can grow and reproduce in space when provided with a well stirred atmosphere and grown at moderate light levels.

Introduction

Every one that has travelled through barren places has experienced the daily burdened of transporting the food and water needed for future days. Today closed ecological life support systems including higher plants holds the best promise to fulfill this ancient dream of a permanent presence of humankind on other planets, and in deep space. To ensure successful plant production and a reliable food source for human crew, it is fundamental to understand how the space factors and an altered physical environment affect the basic processes of a plant's physiology.

The Micro Ecological Life Support System Alternative (MELiSSA) is a model system for advanced life support based on diffe-rent microbial species and higher plants (Binot et al. , 1994; Poughon et al., 2009). In the Literature Study of Higher Plants in Space for MELiSSA (LiRHiPliSME) project, contributing to the MELiSSA Phase 2 - Preliminary Flight Experiments, literature has been reviewed to assemble the relevant knowledge within space plant research. The main objective of LiRHiPliSME was to establish an understanding of the current knowledge within space plant biology and identify the need for future scientific research activities required before higher plants can be included in regenerative life support systems. The project has been focusing on the existing research describing the effects on higher plants exposed to three physical factors on the Moon and Mars that are different from conditions on the Earth:

• Gravity • Radiation • Magnetic field

The MELiSSA loop and a scheme of the literature review process are shown in Figures 1 and 2. The LiRHiPliSME study started asses-sing the plant sub-levels, which then lay the groundwork for evaluation of the whole plant perspective.

Conclusions from literature review

In general, the available information regarding effects of the space environment on plant growth and metabolism is inconclusive and suffers from limitations in available flight hardware, sensor technology and research facilities that simulate space conditions. However, based on the available literature, two main conclusions can be drawn:

- Plants have demonstrated their ability to grow and reproduce in space
  -> A number of long term experiments with plants have been successfully performed in space (Merkys et al., 1984; (Ivanova, Bercovich et al. 1993; Sychev, Shepelev et al. 2001).
- Hardware is of great importance
  -> Satisfactory environmental control is essential to grow healthy plants in space and under reduced gravity conditions, especially atmosphere control (e.g. ethylene scrub,) and air circulation both at canopy level and in the root zone (Musgrave, Kuang et al. 1998; Porterfield 2002; Kitaya, Kawai et al. 2003; Liao 2004).

Through the literature review, interviews of scientists and discussions in the LiRHiPliSME working group, it was identified that future investigation should prioritise the fundamental processes required to ensure long term sustainable plant production in space; i.e. long term effects of the space environment on the processes of photosynthesis, gas exchange, transport of water and solutes and stability of the plant genome.

Requirements for future research activities on higher plants in space

The primary requirement for future research activities on higher plants in space is to reveal the effects of the space environment on fundamental plant processes. The knowledge building process should coincide with given priorities for technology development to complement the research activities. This primary requirement can be achieved through a set of secondary requirements:

- selection of species and definition of their nominal conditions
- standardisation of experimental design
- low chronic radiation experiments
- graded gravity experiments

Future work on ground and in space

In Space, the two main factors affecting plant growth and development are reduced gravity and space radiation. The most frequently reported effects of a reduced gravity environment on plant physiology are linked to changes in the plants physical environment. As an example, the lack of buoyancy driven thermal convection (BDTC) in microgravity and consequent increase in boundary layer thickness causes biophysical limitations on the processes of gas exchange and physiological transport in higher plants (Porterfield 2002).

In future research activities it is crucial to work with a standardised experimental design, and satisfactory environmental control and monitoring of environmental conditions. Moreover, with limited or no sample return, remote sensing diagnosis of plant health is needed. Such remote sensing diagnosis could include various imaging techniques and sensors for surveillance of nutrient availability and plant water status. Overall focus in the future work must be on the whole plant, using food crops as well as model plants. All possible scientific knowledge should be uncovered on ground before proceeding to space experiments. The requirements for future research activities within space plant biology, formed as a set of building blocks to obtain the scientific readiness to allow for further development of enclosed regenerative life support systems including higher plants, is presented in figure 3.

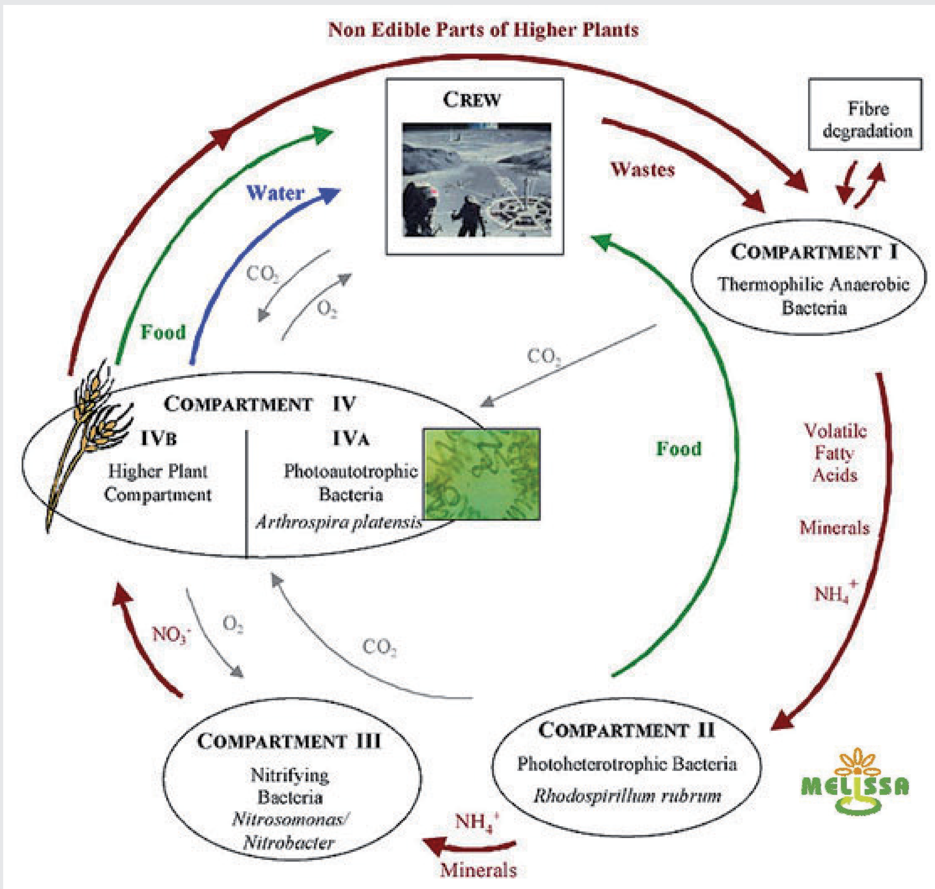


Figure 1. MELiSSA loop concept (from Gòdia et al., 2002).

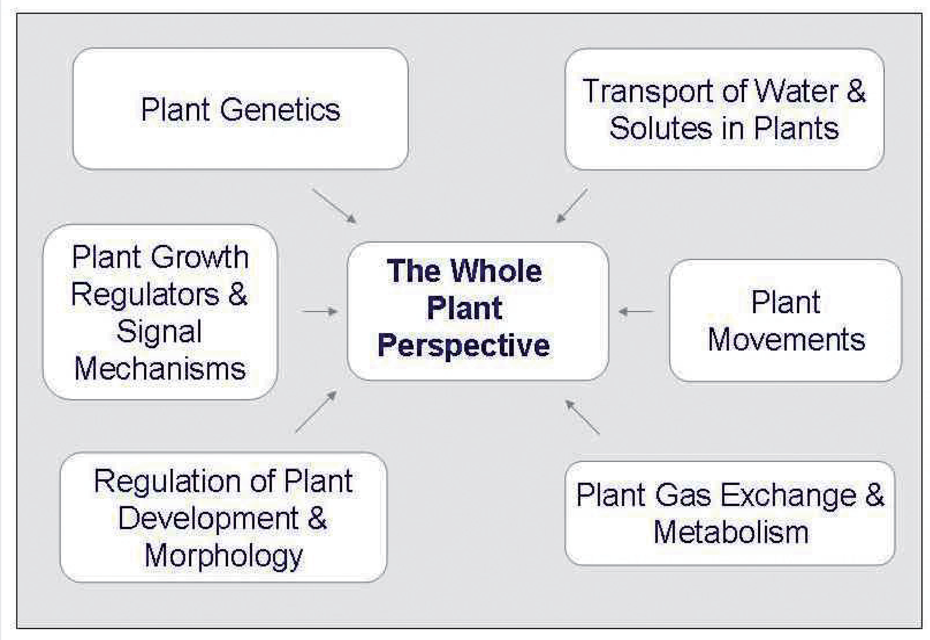


Figure 2. LiRHiPliSME Project Scheme.

References

1. Binot, R. A., Tamponnet, C., and Lasseur, Ch. Biological life support for manned missions by ESA. Advances in Space Research 14 (11), 71-74 (1994).
2. Godia, F., Albiol, J., Montesinos, J. L., Pérez, J., Creus, N., Cabello, F., Mengual, X., Montras, A. and Lasseur, C. MELiSSA: a loop of interconnected bioreactors to develop life support in space. Journal of Biotechnology 99 (3), 319-330 (2002).
3. Ivanova, T.N., Bercovich, Y.A., Mashinskiy, A.L., and Meleshko, G.I. The 1st space vegetables have been grown in the SVET greenhouse using controlled environmental conditions. Acta Astronaut. 29, 639-644 (1993).
4. Kitaya, Y., Kawai, M., Tsuruyama, J., Takahashi, H., Tani, A., Goto, E., Saito, T. and Kiyota, M. The effect of gravity on surface temperatures of plant leaves. Plant Cell Environ. 26, 497-503 (2003).
5. Liao, J., Liu, G., Monje, O, Stutte, G. W. and Porterfield, D. M. Induction of hypoxic root metabolism results from physical limitations in O2 bioavailability in microgravity. Advances in Space Research 34, 1579-1584 (2004).
6. Merkys, A.J., Laurinavičius, R.S.and Švegždienea, D.V. Plant growth, development and embryogenesis during Salyut-7 flight. Advances in Space Research 4 (10), 55-63 (1984).
7. Musgrave, M. E., Kuang, A., Brown, C. S. and Matthews, S. W. Changes in Arabidopsis leaf ultrastructure, chlorophyll and carbohydrate content during space flight depend on ventilation. Annals of Botany 81, 503-512 (1998).
8. Porterfield, D.M. The biophysical limitations in physiological transport and exchange in plants grown in microgravity. J Plant Growth Regul 21, 177-190 (2002).
9. Poughon, L., Farges, B., Dussap, C. G., Godia, F. and Lasseur Ch. Simulation of the MELiSSA closed loop system as a tool to define its integration strategy. Advances in Space Research 44 (12), 1392-1403 (2009).
10. Sychev, V.N., Shepelev, E.Y., Meleshko, G.I., Gurieva, T.S., Levinskikh, M.A., Podolsky, I.G., Dadasheva, O.A. and Popov, V.V. Main characteristics of biological components of developing life support system observed during the experiments aboard orbital complex MIR. In: Nelson, M. (Ed.), Space Life Sciences: Closed Ecological Systems: Earth and Space Applications. Elsevier Science Bv, Amsterdam, pp. 1529-1534 (2001).

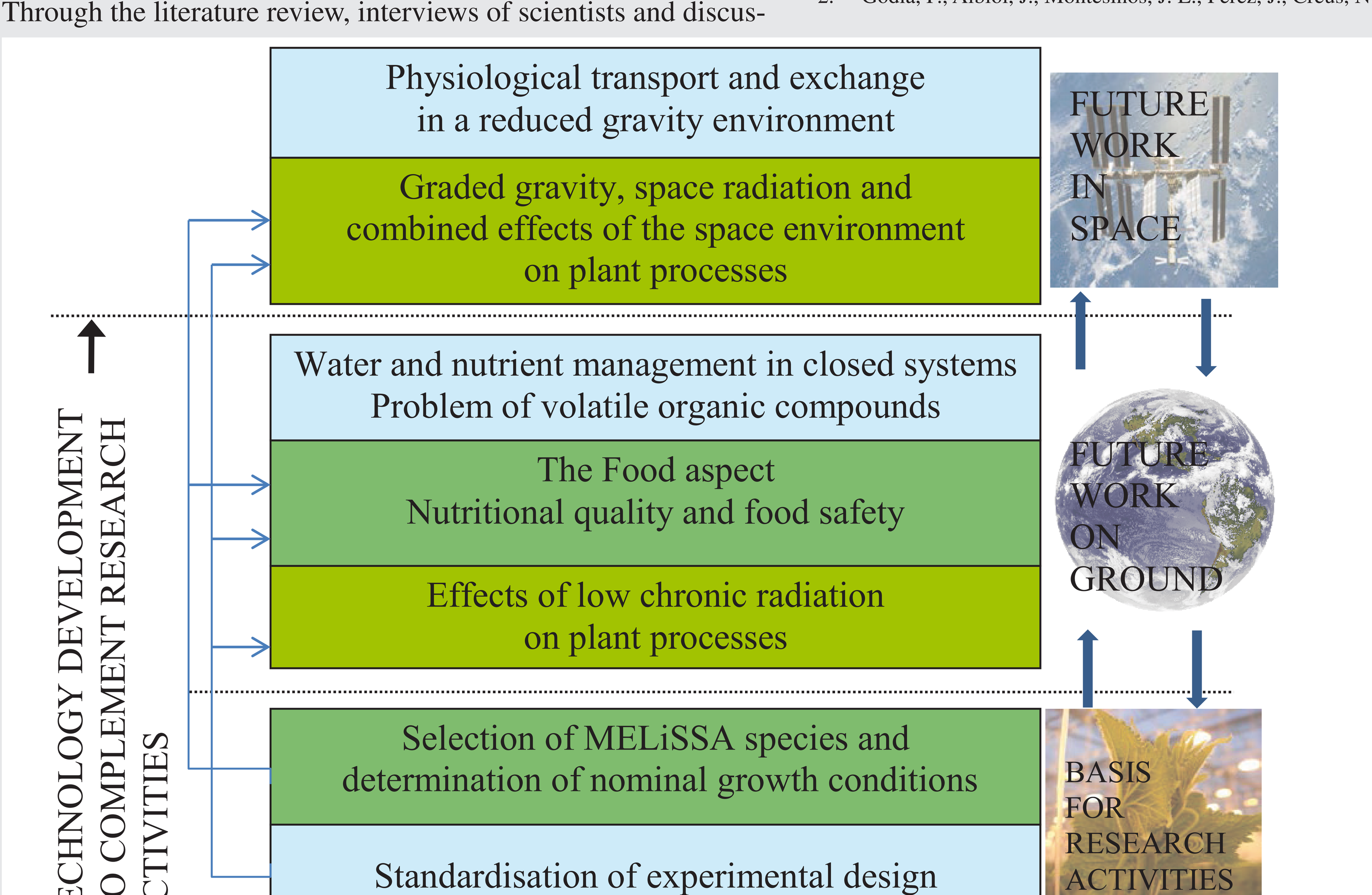
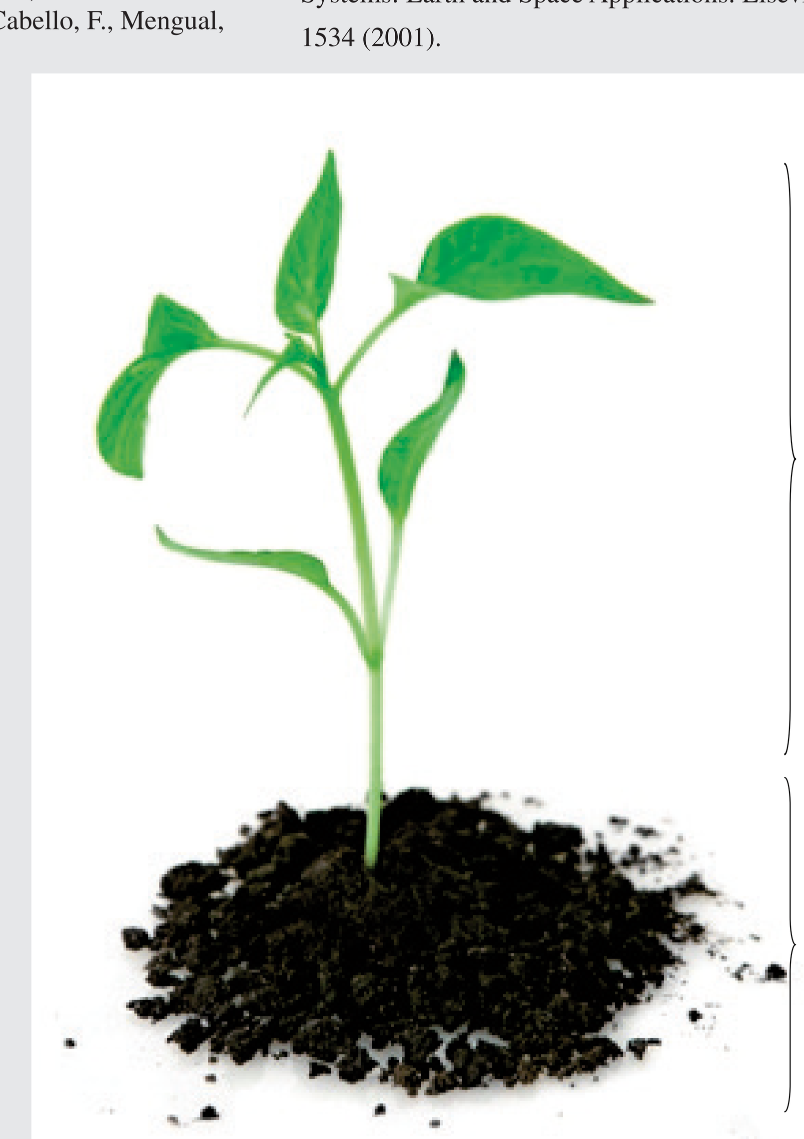


Figure 3. Building blocks (main groups of requirements) for future research activities on higher plants in space. The green boxes describe plant related activities, with the scientific objectives in light green. The blue boxes describe more practical and technological requirements.



Effects of graded gravity, space radiation and combined effects on primary plant processes:

- Nutritional quality
- Biomass production
- Photosynthesis and gas exchange
- Gene expression profile
- Genome stability
- Morphology
- Hormonal interactions

- Transport of water and solutes
- Physiological transport and exchange
- Ventilation in the root zone

Figure 4. Research objectives for future research in space plant biology.