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What Horticulture and Space Exploration Can Learn From Each Other: The Mission to Mars Initiative in the Netherlands

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Abstract

The horticulture sector in the Netherlands is a global leader due to technological advancements, knowledge of greenhouse cultivation with high productivities and low resource usage, and entrepreneurship. The Netherlands is the second largest exporter of vegetables in the world, and more than half of its land area is used for agriculture with some greenhouse complexes covering 175 acres. However, to retain this leading position, the sector has acknowledged that it needs to keep innovating. To further reduce waste and environmental impact, an innovative production strategy is being developed to support a circular economy: the circular greenhouse. LDE Greenport Hub is an entity of the strategic alliance of the Universities of Leiden, Delft and Erasmus and is focused on horticulture scientific research and education in collaboration with major horticulture industry partners (such as sector association LTO Glaskracht). It has initiated 'Mission to Mars', a program to boost innovation and development of the circular greenhouse by adopting concepts and technologies from space. Space is inherently focused on circularity because of scarce resources. A good example is the MELiSSA concept of the European Space Agency in which human waste is broken down into nutrients for crops and algae by a series of bioreactors. The crops and algae consequently provide food and oxygen for the crew again. The Mission to Mars program started with a lecture series in the beginning of 2018 at the World Horti Center, a horticulture business and innovation center in Naaldwijk. In seven lectures different aspects of sustainability and circularity were explored together with researchers, students, growers and horticulturists. The lectures covered (1) energy, (2) water, (3) lighting and climate, (4) soil, substrate and plant health, (5) material and energy streams, (6) digitization and automation, and (7) urban and vertical farming. It quickly became clear that not only terrestrial horticulture could benefit from space technologies, but that human space exploration could equally benefit from the technical and tacit knowledge of growers and horticulturists for food production in space. A list of potential research topics was identified. These topics are to be explored in a follow-up ESA Innovation Exchange, together with space technology partner ICE Cubes. The goal is to go beyond the circular greenhouse and demonstrate how space itself can be an environment for plant biology innovation, and hence increase future food security on Earth.
Keywords: Horticulture; Circular greenhouse; Innovation; Technology transfer; Space farming; Space biology

1. Introduction

Agriculture is currently faced with a series of accumulating challenges that jeopardize both its capacity to provide the world with adequate food and its own future. Through the combination of population growth and development, there's an ever-increasing food demand. The production of some crops, such as for example cereals, has to increase more than 40% over a 40-year timespan to address this demand. Climate change has already started disrupting food production throughout the world. If current trends continue, the latest projections of climate change indicate uncontrollable shifts in arable land through drought and erosion. Additionally, the combination of large-scale industrial agriculture (in combination with industrialization and rapid urbanization) has caused significant environmental degradation with e.g. numbers of pollinating insects rapidly dwindling. [1,2,3,4] Finally, the world is also faced with encroaching resource depletion with the prospect of gradually increasing prices and, in the long run, problematic scarcity [5].

In many ways, circular agriculture offers a way out of these manifold problems by redirecting and repurposing waste streams and integrating side streams. Such increased efficiency can lead to increased productivity with a reduced impact on the environment [6]. Moreover, circular systems are typically characterized by a higher degree of technological control and as such they be better adapted to changing environments.

The Dutch horticulture sector currently holds a leading position in the world.[7] However, this might lead to acquiescence and a shortfall in innovation. Additionally, there might be a lack of precise knowledge what true circular horticulture entails, with growers believing they've already achieved circularity. As such, there's a pertinent need for innovation in the horticulture sector towards deeply circular food growing systems.

While it is clear that food production on Earth is undergoing rapid transformation, research on growing food in outer space is also intensifying. With increasing human activity in low earth orbit and prospects for lunar missions and beyond, regenerative life support systems producing fresh food become an unavoidable necessity [8]. There's a range of different existing research projects either focusing on specific plant biology challenges in space (e.g. NASA's VEGGIE system) or entire regenerative ecosystems being tested on Earth (e.g. MELiSSA in Europe and Lunar Palace in China) [9,10]. Because of the advanced technological nature of space habitats and a focus on circularity therein, there's potentially a range of technologies that could be applied for farming on Earth. All the above-mentioned research programs operate on a lab scale, and crop production is often quite limited. But we should not only focus on science experiments, but also move towards learning to grow large quantities of food in space to secure a more permanent and sustainable human presence in space. Biosphere 2 in Arizona was an example of an enclosed regenerative ecosystem [8] with a relatively large agricultural area, 2500 m^2 in total for 8 inhabitants. The experiment reached high crop production rates and complete food sufficiency during its second mission. However, the Biosphere 2 ecosystem as a whole displayed large fluctuations and experienced a range of technical and ecological issues such as, for example, all pollinating insects dying off, population explosions of ants and cockroaches, and invasive plants overtaking parts of the ecosystems. As a result, the entire system needed very intensive maintenance by its inhabitants. It's precisely in the challenge to sustain a stable and efficient production of large amounts of food, that space scientists and engineers could benefit from integrating the experience and tacit expertise of growers.

2. Mission to Mars program

In order to facilitate collaborations between the domains of horticulture and space exploration, the Mission to Mars program was set up by LDE Greenport Hub in cooperation with the horticulture growers association LTO Glaskracht [11]. The objectives of the Mission to Mars program are:

- To bring together the two worlds of horticulture and space exploration, from a scientific perspective.
- This is done under the assumption that confrontation with different perspectives and approaches leads to innovation.
- However, simply bringing together is not enough. What is additionally needed is connecting the two different knowledge networks (horticulture and space), and connecting scientific and operational knowledge (within and between domains).

The first activity of the program consisted of a lecture series which was presented at the World Horti Center (WHC) in Naaldwijk in The Netherlands. Naaldwijk is situated in the area of Westland and positions itself as the world's center of the high-tech greenhouse industry. In-depth knowledge from the advanced Dutch greenhouse sector was secured by having both LTO Glaskracht and the World Horti Center with its network of companies as key partners of the lecture series. This was combined with the scientific knowledge of the three LDE universities of (Leiden University, Delft University of Technology, Erasmus University) in the domains of biology, space technology and innovation management. As such, the bridge between the worlds of horticulture and space exploration could be made from a multilayered perspective.

The lecture program took ´Voorwaarts Mars´ published by LTO Glaskracht in 2017 as a departure point [12]. The book makes a case to look at the development of agriculture in space and its inherent need for circularity as a template to reach the goal of the circular greenhouse concept. Through a series of interviews, different stakeholders are interviewed about different challenges involved. The lecture series dived deeper into the matter, and explored different technologies and approaches for greenhouse circularity, both from the horticulture and space engineering perspective. Seven different topics were selected, and these were presented over the course of two months during weekly two-hour sessions. Each session consisted of an hour-long intro about the topic in which relevant space concepts and biological principles were elucidated. This allowed the audience to get more acquainted with both space engineering and scientific principles underpinning plant biology. This was followed by a talk on the same session topic given by expert from the horticulture business field. This gave the audience a deeper and also more pragmatic perspective on horticulture innovation. The seven discussed topics were:

1. Energy
2. Water
3. Lighting and climate
4. Soil, substrate and plant health
5. Material and energy streams
6. Digitization and automation
7. Urban and vertical farming

Each session was concluded by an open discussion in which the audience was invited to contribute ideas for a research agenda. The objective of this research agenda was to develop the circular greenhouse concept and to bring academic research into it.

4. Results

The lecture series was well attended, with around 50 person per lecture and more than 100 participants at the finale lecture during the opening of the World Horti Center on March 7, 2018. The audience consisted of a mix of growers, academic researchers, students and technical staff of horticulture and supply companies (Fig. 1). Techniques unknown to the horticulture sector, but familiar to space exploration, were gradually introduced to the audience throughout the entire lecture series. Exposing the horticulture community to a different environment opened up creativity and made new discussions possible, including questioning the sector's status quo. Simultaneously, there was also a knowledge transfer in the other direction. Instead of reducing research for food production in space to plant biology experiments in lab settings, the horticulture sector can take this challenge to a real production level. What would it take to produce sufficiently large amounts of food for a group of people in outer space, all year round? Some key examples of what both worlds can learn from each other are listed below.

Fig. 1. Mission to Mars lecture 5 on material and energy streams at the World Horti Center in Naaldwijk on 23 February 2018. Photo Delft University of Technology.

Firstly, some examples of what horticulture can learn from space:

- General circular thinking
- Waste recycling (e.g. MELiSSA)
- Sensing/control of water and climate
- Automation, robotics, AI
- Space optimization

Secondly, some examples of what space can learn from horticulture:

- Large-scale food production
- Real-time nutrient sensing
- Lighting technology
- Biological disease control

At the end of the lecture series a range of ideas had been collected to be used as the starting point for a shared research agenda. Here are some selected research topics that were suggested by the participants during the discussion sessions at the end of each session:

- Relate DNA to growth characteristics. Plant characterization and modeling is getting increasingly important in the agricultural sector in order to cultivate optimized crops under exactly the right circumstances. At the same time this is also a crucial research component in order to create reliable biological life support systems in space.
- Hydroponics and aeroponics in low/micro gravity conditions (Mars, Moon, space station). To grow large quantities of fresh food in space, efficient plant grow systems need to be used. Hydroponics and aeroponics seem especially suited for this because of the very high level of control of water quality and nutrient supply. Moreover, in microgravity conditions, aeroponics is a very compatible solution to provide water to plant roots.
- Low cost sensors for real-time ion measurement (in water) are crucial for more detailed and faster analysis of entire water circulation systems. This will help in guarding water quality and more refined nutrient delivery.
- We need to understand more about the microbiology of substrate/water and their effects on plant health and productivity. This could lead to better techniques to inoculate substrate/water with the right mix of micro-organisms. This could then drastically improve growing techniques and lead to more resilient

cultivation methods, both on Earth and in space.

- Additional research on controlled lighting techniques for plant growth. This is a very active field in the domain of horticulture. With so-called ‘light recipes’ plants with specific nutritional and morphological qualities can be grown. This technology would be ideal in a space context for flexible and adaptive growing regimes.
- More research on efficient extraction of accumulated sodium out of the water in circular plant growth systems. This includes processing of brine resulting from reverse osmosis. At the ISS a lot of expertise is being used to recycle as much of the water as possible. This knowledge has direct relevance for water purification systems on Earth.

The Mission to Mars program received ample media attention in the Netherlands with several articles and interviews in printed press, online and in a radio show (Fig. 2). Hillenraad is a renowned Dutch magazine ranking the Top 100 companies in Horticulture. In 2018 their ambition to mobilize the younger generation (Sub40) was connected to the ambition of growing in space. They dedicated their Sub40 selection to the theme of farming on Mars. A joint event was organized at Delft University of Technology to connect and integrate both the Mission to Mars and Hillenraad Sub40 programs. After giving the lecture series, the first author received subsequent invites for talks in the agri-food sector in the Netherlands and beyond (Cross-KIC EIT Food & Health in Rotterdam, Food Friction in Arnhem, Flanders FOOD event in Ghent, etc.)

Fig. 2. The Mission to Mars lecture program received ample media coverage in the Netherlands, both in general press and specialized publications. Screenshots of articles in Vakblad van de Bloemisterij (May 2018) and Algemeen Dagblad (9 January 2018).

5. Discussion

Bringing together the two worlds of space exploration and horticulture points to an important difference between the scientific research tradition in space and commercial crop production expertise on earth. However, future manned space missions will require a form of food production in space. The research driven approach from space exploration seems to miss a lot of the practical attitude and tacit knowledge of the production-oriented growers. On the other hand, there´s also a range of technical concepts currently used in space that could be beneficial for horticulture systems on Earth. A combination of both worlds seems to be a viable way forward. Currently, horticulture and space science are still quite removed from each other. More interaction and personal meetings are needed to familiarize both worlds with each other.

The lecture series has provided the foundations for follow-up work, and currently there’s a range of new Mission to Mars initiatives that have been scheduled. The lecture series drew the attention of ESA/ESTEC, and as a consequence an ESA Innovation Exchange is being envisioned, specifically on the crossover possibilities between horticulture and space technology. Microgravity research in space can be an interesting context for horticulture innovation, and with this in mind, the Mission to Mars program has partnered with ICE Cubes to explore possibilities for open access to space for Dutch growers. Delft University of Technology is also interested in setting up a MOOC (massive open online course) as a follow-up to the lectures, to bring the message to a more global audience.

6. Conclusions

The two worlds of horticulture and space exploration are not naturally connected, but there's opportunity in connecting both. To create a solid interconnection, a good understanding of the contents and networks of both worlds needs to be in place. The form of a lecture series, resulting in a research agenda with a combination of science and technological business insights, seems to be a promising starting point. The common theme of circularity within horticulture and space exploration creates a concrete learning opportunity for both. For horticulture, insights in new methodologies and technologies, and for space exploration, insights from professional large-scale food production. Professionals from both worlds were able to recognize the value of their own knowledge and solutions for each other. Learning about different approaches and technologies created new insights and provided fresh perspectives on one's personal practice. It also helped identify opportunities in previously unknown domains. The lecture series has created the framework for further exploration and new collaborative projects. With both the interest of ESA and the horticulture sector for follow-up, a more structured relationship can be envisioned.

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