Construction of a vertical NFT hydroponics tower in the Mars Desert Research Station and evaluation of the effects of extreme temperature variations on system outputs

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Abstract

This report presents the experimental plan of a project aimed at, on the one hand, the construction of a fully functional vertical tower hydroponics system in the MDRS's GreenHab, and on the other hand, an experiment monitoring the different consequences that extreme heat variations in a closed space setting can have on a hydroponics system such as the one that will be constructed.

1 Introduction

Hydroponics is a soil-less, water-based plant growing technique, that allows for high yields, fast growth and minimal losses, and that has become second only to traditional soil based growing methods. While it may seem new and experimental, there is evidence that hydroponic methods have been used for millennia, dating back to the Hanging Gardens of Babylon, the Aztecs, and to ancient Chinese cultures. Today, this type of growing is in widespread use in all research laboratories and scientific greenhouses, as well as being a frequent system for growing certain plants of commercial use.

Modern hydroponic systems are technically far superior to traditional agricultural methods, both in surface yields and water and nutrient conservation. Their impact on the environment, while still existing, is very diminished. Indeed, while these systems can consume a lot of energy for lighting, they offer the advantage of having zero nutrient leakage into the environment, and therefore zero ecosystem pollution. One extensive study [1] has found these numbers when comparing hydroponics to traditional agriculture:

- 11 times higher yields due to vertical stacking and multiple harvests
- 13 times lower water loss, all remaining losses being only due to evapotranspiration
- No loss of nutrients

These advantages however come at the price of much higher energy usage (up to 82x, mainly for lighting), making hydroponics most efficient in places where light and energy are abundant, and water is scarce. For this reason, hydroponics has naturally been pushing agriculture further and further into the previously uncultivated, sun-baked and arid zones of our planet.

For the same reasons hydroponics is so useful in opening up new land to agriculture, it also presents itself as the only possible suitor for growing future space vegetables. Indeed, the needs of a space plantation align almost perfectly with the advantages hydroponics has to offer. A space greenhouse needs to be as economical as possible on all fronts : space, water, and nutrients usage, cleanliness, low risk of disease and high yields per plant. Hydroponics is a solution to every one of those factors, through its high yields, nearly 100% water and nutrients usage, possibility to grow all types of plants including the most efficient ones, lack of soil and closed-system form, and optimal hygiene.

Therefore, such a system definitely has its place in the GreenHub of the MDRS. A form of it already exists there, but it is a passive system consisting of nutrient

Figure 1: Hydroponics towers.

filled boxes with small holes in which plants grow without any real optimisation. It is an acceptable system for minor scientific research, but its format makes it tedious to handle, exposed to risk of root rot and operational mistakes since many separate boxes have to be handled. It is also unsuitable for the higher volumes of production that are needed to sustain a full crew, as it takes up large amounts of horizontal space. A different, more complete system needs to be implemented.

2 Objectives

The purpose of this project is therefore the building of a fully equiped hydroponics growing tower complex, a system based on a vertical nutrient film technique (NFT) that will be able to accommodate up to 60 plants in three separate growing towers while allowing for three different nutrient solutions to be used, opening the door to different experimental or optimisational conditions.

The towers will be built from scratch, using, as main materials, PVC pipes, hydroponic growing nets, three small pumps, and three large opaque solution reservoirs. This focus on very basic building materials, along with the small space of the GreenHab and the very short time in which the system will need to be built, will simulate the conditions in which Martian astronauts would find themselves in the case of a systems failure in which they'd need to quickly replace their food production system.

Alongside of the construction of the tower, lettuce seeds and other leafy plant seeds will be germinated in rockwool cubes, and transplanted into the finished towers, after one short week if possible. Some of the produce will hopefully be harvested near the end of our stay for the crew to enjoy, while the rest will be left for the next crew to take on. In addition to this, small plants will be purchased before the beginning of the experiment and transplanted into the towers as soon as they are built. Other, fruiting plants may be sprouted at the beginning of the experiment, and grown in one of the three towers for later crews to enjoy.

Given the short experimentation time, it will be impossible to experiment on long-term variables, such as nutrient or light intake and their effects on plant health and yield. However, one highly contextual factor of extreme importance will be closely monitored : temperature, and more specifically water temperature, as it is very important in hydroponic cultures, particularly so in a Martian setting where temperature variations are extreme and protection is difficult.

Water temperature is a big risk factor because it can lead to root rot (4), growth deficiencies (2,3), as well as nutrient decomposition if the temperature is too high. This can lead to catastrophic situations, especially in the small growing space of a Mars colony, in which disease spreads quickly and nutrients are scarce. In addition, low water temperatures can lead to stunted growth, leaf decoloration and death of seedlings. In a Martian setting, temperatures vary between both these extremes, and if the greenhouse atmosphere isn't regulated properly, the plants will be affected.

To monitor these risks, both leafy towers will be initially prepared in the same way (same plants, same classic Yoshida-type nutient solution, same hygiene precautions). One of them will be the experimental tower, in which low temperatures at night and high temperatures during the day will be simulated, while the other one will be the control tower, closely monitored for temperature, especially water temperature, which will be regulated as needed to stay as close as possible to the optimal 24°C. Additionally, two batches of seedlings will be grown under the same conditions : one left to suffer at the temperature variations, and one closely monitored by a heating mat set to the right temperature.

The temperature of the MDRS GreenHab is regulated by a thermostat. Except in a case of system malfunction, this will allow the control tower to remain at a stable temperature without the need of any additional tampering. The same goes for the control group of seedlings. For the experimental tower and seedlings, different methods of temperature regulation will be used, including a heated mat, a heater, moving the tower around in the greenhouse to position it in the most extreme zones, placing it outside, and cooling or heating the nutrient solution. Therefore, the experimental tower will experience temperatures ranging from 5°C to 40°C, while the control tower will stay in the zone between 20°C and 26°C.

3 Hypothesis

At the end of the experiment, we expect to observe the following :

- Stunted growth in the experimental seedlings (and possible death), and stunted growth in the experimental tower [3, 4]
- Possible formation and spread of root rot in the experimental tower [2]
- Possible but unlikely degradation of nutrients leading to visible deficiency symptoms in the plants in the experimental tower
- Optimal growth in the control tower
- General size and health differences between the experimental and control towers

4 Modus operandi

The first week will be dedicated, on the one hand, to the building of the towers, and on the other hand to the germination of seeds and selection of seedlings.

Day 0

- Purchase of all necessary goods
- Arrival and delivery of goods to the MDRS • Visit of the GreenHab

Day 1

- Setup of all building material in the GreenHab • Checklist, troubleshooting
- Setup of the germination area
- Planting of different seeds in rockwool cubes

Day 2

- Formation of hydroponic towers out of the 3 PVC pipes

Day 3

- Bucket modifications (cutout, sealing, fixation)
- Tower bottom modifications (cutout, fixation)
- Rain cover formation and installment
- Electricity management
- Pump installment and troubleshooting

Day 4

- Placement of the towers in their buckets
- Basket placement
- Leakage checks
- Debit checks
- Timer setup
- Test run 2h

Day 5

- Troubleshooting

Day 6

- pH-meter setup
- Nutrient solution testing ne adjusting
- Selection of optimal nutrient combination

Day 7

- Sprout selection
- Growing medium setup
- Nutrient solution setup
- Transplantation

The **second week** will be dedicated to the optimisation of early growth stages, temperature monitoring, and water temperature control for the optimised tower.

Figure 2:

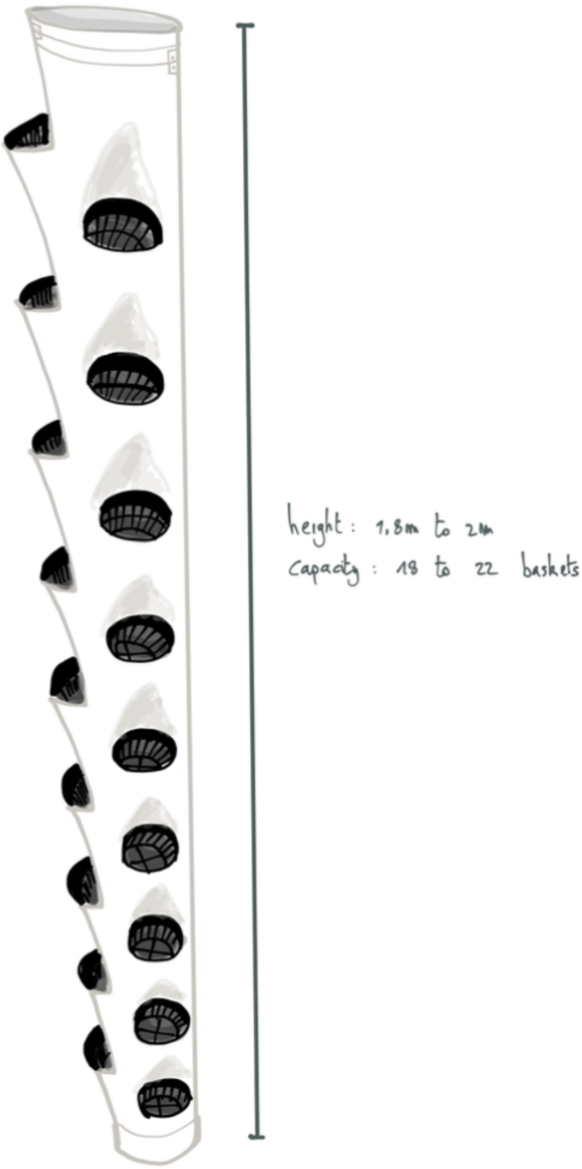
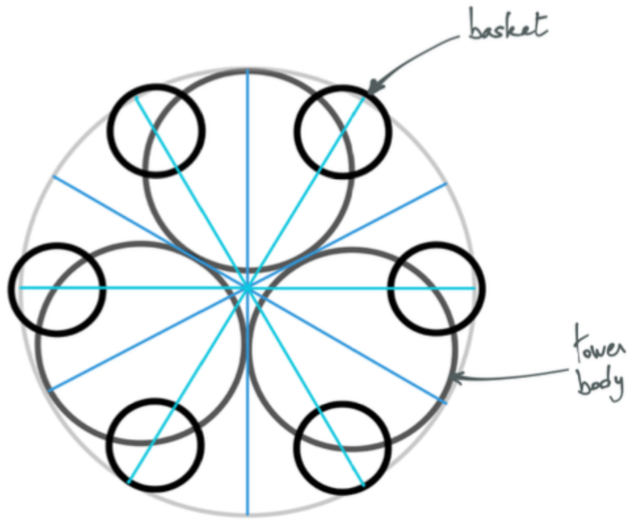


Figure 3:

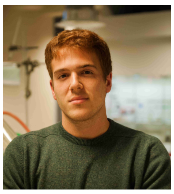


5 First draft

The model of a single tower, with two columns of ten baskets each, is illustrated in Figures 2 and 1. Every basket is inserted into a preformed opening, which has been moulded by slicing the plastic, heating it up and shaping it to suit the basket size. The water is pumped to the top of the tower by an inside hose, where it is dispersed by a so-called 'rain cap' which serves to break the continuous flow into droplets, easier to access for the plants. Those droplets run down the plastic and over the baskets, still inside the tower, where they are absorbed by the plants' roots, hanging inside. The flow is timed to turn on and off every fifteen minutes, to allow for respiration and to prevent rot. This system allows for optimal oxygenation of both water and roots, since the former is agitated by the falling drops, and the latter is continuously exposed to air, unlike in many other systems.

The arrangement of three towers in a triangular shape allows for optimal light exposition of all baskets. The entire system assumes a very geometric shape, as shown below. This is shown in Figure 3

About the author



Mario Sundic is a 21 year old bioengineering student. Currently finishing his bachelor's degree in Belgium, he plans to study plant and microbial genetics abroad, with the aim of working in an innovative biotech company. His passions include ecology, biotechnology, photography, and languages, as he is currently fluent in four languages and learning a fifth one. In addition to this, he is an avid traveler, having visited over 25 countries by his own means, and counting. He will serve the double role of Crew Journalist and GreenHab Officer in the MDRS.

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