Mars Greenhouse Research

Baseline Information:

- Abstract

Anthropogenic Requirements:

- Life Support

- Mathematical Portioning

- Daily Human Nutritional Values

Historical Precedents:

- Salyut Missions

- Soyuz Missions

- Mir Station

- International Space Station

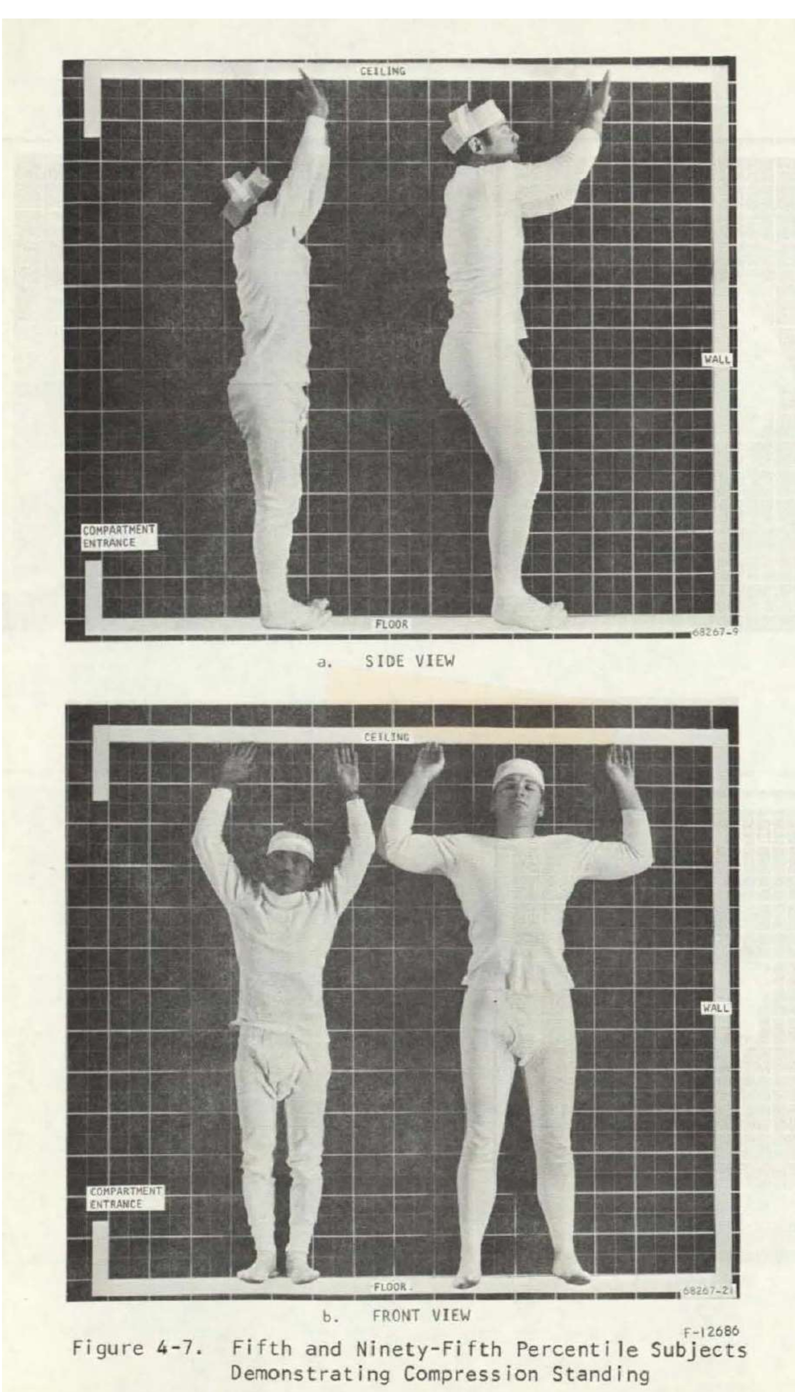

Figure 4-7. Fifth and Ninety-Fifth Percentile Subjects Demonstrating Compression Standing

Baseline Information:

- Abstract

This research document is primarily focused on outlining a collection of plants that are considered viable in order to sustain a crew of at least seven for multiple years on the Martian surface. This analysis includes the science behind why these specific plants have been chosen, as well as the effects that these species will have physically and psychologically on the crew. In addition to this, further examination regarding the nutritional needs of both the human and the vegetation will be analyzed in order to mold the design of a greenhouse structure for the planet Mars.

Anthropogenic Requirements (Daily):

- Life Support

Maintaining a consistent level of nutrition is essential to enabling a higher level of productivity for the crew and their accouterments. A closer inspection on what exactly these nutritional requirements are can give grounds to establishing how many plants, and which types of plants, are needed to fulfill said demands. Advanced Closed Loop Systems (ACLS) will allow for each individual greenhouse to maintain its own life support system over an indefinite period of time, thereby allowing a consistent stream of nutrition to the crew.

- Mathematical Portioning

Plants being grown in a Martian greenhouse will serve two purposes; **produce Oxygen/ reduce CO_2 levels, as well as producing food**. Plants produce O_2 at a rate of .05 milliliters per hour per cm^2 of leaf area. Likewise, humans consume 50 liters of oxygen per hour. However, humans only produce half of the CO_2 needed to sustain an equal amount of plants. Fortunately, Mars' atmosphere is comprised mainly of CO_2, thereby allowing a controlled siphon mechanism to provide the additional levels of CO_2 to maintain any number of plants. The following metrics are important values that need to be met daily in order to provide a consistent level of nutrition and healthy lifestyle.

- Daily Human Nutritional Values

- Oxygen Input: 0.83 kilograms
- Food Input: 0.62 kilograms
- Water Input: 3.56 kilograms
- Carbon Dioxide Output: 1.00 kilograms
- Metabolic Solids Output: 0.11 kilograms
- Water Output: 29.95 kilograms
- Useful Biomass: 1,300 grams
- Calories: 1,800
- Protein: 30 - 50 grams
- Fat: 20 - 25 gram
- Calcium: 1,000 milligrams
- Carbohydrates: 400 - 500 grams
- Vitamin D: 10 milligrams
- Vitamin C: 70 milligrams
- Vitamin B: 1 gram
- Vitamin B2: 1 gram
- Carotene: 3 - 4 milligrams
- Potassium: 2,500 - 4,000 milligrams
- Magnesium: 100 - 300 milligrams
- Phosphorus: 100 - 150 milligrams
- Iron: 10 - 15 milligrams

Historical Precedents:

- Salyut Missions

The Russian Salyut Missions were a series of Soviet Space Stations launched into space between the years 1971 and 1982, with the primary function to conduct scientific experiments, as well as tactical reconnaissance during the Cold War. The former allowed for many of these missions, that being 71 successful trips, to establish the framework for future biological cultivation in space. The following is a catalog of recorded information regarding Salyut's Biological Studies (Mashinsky, p. 5 -7):

- Studies of Unicellular Organisms and Fungi during spaceflight
- Effects of Spaceflight Exposures on Seeds and Plants in Natural Dormancy or Activation
- Radio-biological Studies of Seeds, Tubers, and Turions
- Effects of Extreme Spaceflight Exposures on Developing Plants
- Effects of Spaceflight Factors on Adult Plants
- Ultrastructure of Plant Cells During Spaceflight
- Gravitational Perception and Growth of Plants in Weightlessness
- Long-Term Test Processes for Identification for Spaceflight Effects on Biological Subjects
- Substrates for Plant Cultivation
- Plant Cultivation Technologies
- Enrichment of the Orbital Station Interior with Decorative Plants
- Evaluation of Plant Micro-flora at Manned Spacecraft
- Selection of Plant Sets for Bio-technical Life Support Systems

The information recorded during these missions is nearly half a century old as of the creation of this research document (Fall, 2022). However, several key areas of investigation (**Effects of Spaceflight Exposures on Seeds and Plants in Natural Dormancy or Activation, Gravitational Perception and Growth of Plants in Weightlessness, Plant Cultivation Technologies, and the Selection of Plant Sets for Bio-technical Life Support Systems**) can be paired with modern information and technology in order to formulate a successful approach towards developing autonomous biological cultivation on Mars.

The **Soyuz Missions** are one of the more modern investigations regarding life in space orbit. Initially launched in the early 1960's, the Soyuz Missions are an on-going project from Russia designed to push the boundaries of biological experiments in space. Their progress regarding this field, as well as the work being done on **Mir Station**, will continue to provide vital information that will impact the future of extraterrestrial colonization (Kondyurin, p. 349). Similar studies are also being conducted on the **International Space Station** (ISS).

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Mars Greenhouse Research

Methods for Success:

- Problem Solving

- Nutritional Enhancements

- Addition of Extremophiles

- Harrowing Soil

- Lighting Solutions

Case Studies:

- Microorganism Cultivator

- Microbial Cultivator

- Vazon System

- Biogravistat Device

- Oasis 1A System

- Rodwell Experiment

Element	Pathfinder A-2, Soil [5]	Pathfinder A-4, Soil [5]	Pathfinder A-5, Soil [5]	Viking 1 Lander Site [6]
	Weight %	Weight %	Weight %	Weight %
Carbon [C]	-	-	-	-
Oxygen [O]	42.5	43.9	43.2	-
Sodium [Na]	3.2	3.8	2.6	-
Magnesium[Mg]	5.3	5.5	5.2	5.0 +/- 2.5
Aluminum [Al]	4.2	5.5	5.4	3.0 +/- 0.9
Silicon [Si]	21.6	20.2	20.5	20.9 +/- 2.5
Phosphorus [P]	-	1.5	1.0	-
Sulfur [S]	1.7	2.5	2.2	3.1 +/- 0.5
Chlorine [Cl]	-	0.6	0.6	0.7 +/- 0.3
Potassium [K]	0.5	0.6	0.6	< 0.25
Calcium [Ca]	4.5	3.4	3.8	4.0 +/- 0.8
Titanium [Ti]	0.6	0.7	0.4	0.5 +/- 0.2
Chromium [Cr]	0.2	0.3	0.3	-
Manganese [Mn]	0.4	0.4	0.5	-
Iron [Fe]	15.2	11.2	13.6	12.7 +/- 2.0
Nickel [Ni]	-	-	0.1	-
Not Directly Detected*	-	-	-	50.1 +/- 4.3
Sum	100	100	100	49.9

* Includes H_2O, NaO, CO_2, NO_x, and trace amounts of Rb, Sr, Y and Zr

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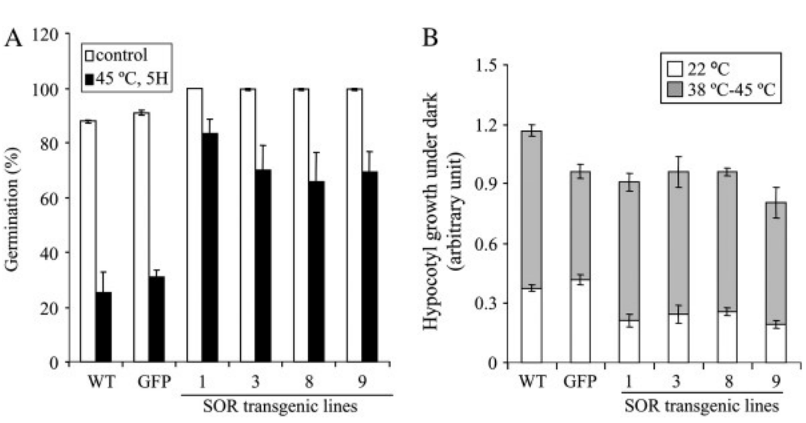

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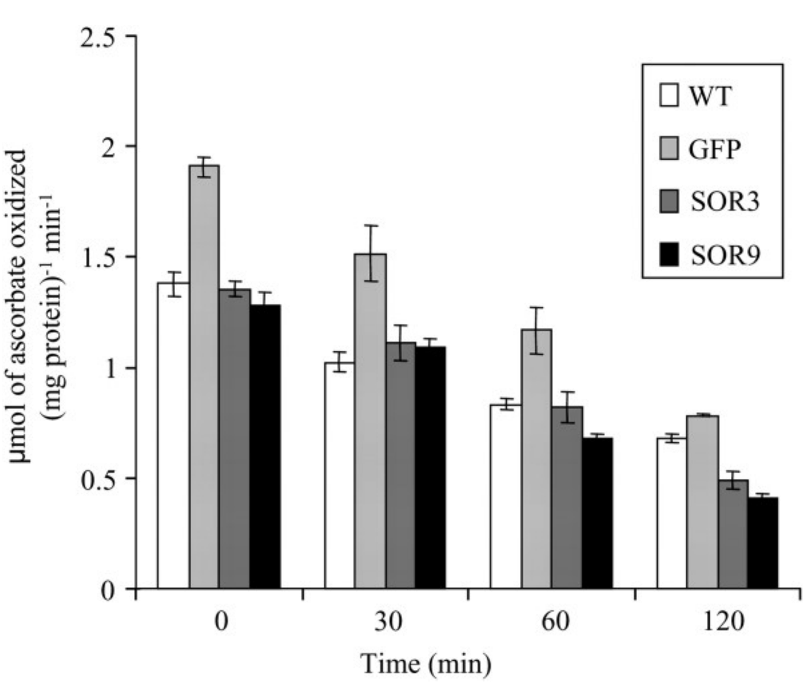

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Methods for Success:

- Problem Solving

In order to develop a living ecosystem that can be operated autonomously, identifying the problems that have the potential to squander said environment need to be established. These are the rudimentary blockades that will prohibit a long-term settlement from flourishing and being considered successful. Through a series of vector optimization methods that utilize various quantitative and qualitative criteria (Nechitailo p.375), these limitations can be brought to the forefront and be given solutions, the **core five** are as follows:

- A lack of sustainable nutrition levels (Vegetation and Anthropogenic)
- A lack of physical space
- A lack of habitable conditions (soil, temperature, air, gravity)
- A lack of water
- A lack of sunlight and other forms of necessary energy

The core five limitations provide the most generic, and at times complex, problems to solve. Below are methods that can be developed through design in hopes of resulting in an outright solution.

- Nutritional Enhancements

Martian regolith (P, Ca, Mg, S, Fe, Zn, Cu, Mo) (McGrath, p. 5) (Image 002) will need to act as a solvent, absorbing additional nutritional enhancements in order to alter its chemical pH level. Due to the higher levels of Iron, an alkaline metal, the pH level of the soil on mars is higher than that on Earth **(average level of 7.2)**. **Introducing ammonium-containing fertilizers** will lower the pH level of the soil over time, a substance that can easily be fabricated through the use of compost and manure. Injecting secondary doses of Nitrogen through ammonium-containing fertilizers is crucial, as Martian regolith does not have the necessary levels of Nitrogen to sustain the **Nitrogen Fixation** process. Without Nitrogen Fixation, plants and other organisms will not be able to grow.

Microorganisms such as **diazotrophs** naturally conduct this procedure, thereby expediting the bio-synthetic portion of the nitrogen cycle, an essential aspect of cultivating organic compounds. The **MELiSSA program** (Micro-Ecological Life Support System Alternative), is a leading research study to support autonomous life support through nitrogen fixation, by which humans and plants can both benefit from.

Additional nutrients can be incorporated into an ammonium-containing fertilizer to further develop the amount of vitamins that can be provided to the plants in Martian greenhouses. Plants comfortable in extreme conditions such as **Alfalfa** are an excellent way to supercharge the regolith, resulting in healthier plants.

- Addition of Extremophiles

Extremophiles are **microscopic organisms** that have significant biological characteristics in allowing them survive in extreme conditions. Although there are millions of genetic strands among billions of organisms, a select few traits could be influential in the next stages of Martian colonization. A series of experiments, involving bio-domes as a constant, revealed two key genes as being highly useful. Those being **pyrococcus furiosus** + **superoxide reductase** (Clay, Spectroscopic Studies). In short, through a developing method of **gene splicing**, these two specific genes can be integrated into the selected plants' DNA in order to establish a higher level of **cold resistance** as well as making the plant **rely less on consistent watering** (Im, Expression of Plant Physiology, p. 893 - 904) (Image 003 + Image 004).

This is possible through synthetically reducing **cytosolic Reactive Oxygen Species (ROS)**, which if left unintended will result in cell death due to a high level of stress. Both of these traits would be considered necessary, for the inaugural trip, to make a sustainable colony in the Martian environment with regards to year round cultivation.

- Harrowing Soil

The Martian soil differs throughout the varying regions of the planet, but generally is a clay based material that is **dense and thick**. Implementing strategies in order to transform the soil into a **sandy loam-like consistency** will pay dividends for the future of a Martian colony. Initial steps include growing a series of **secondary species** in the same area of soil, allowing the two plant types to interact uniquely with Martian regolith, thereby breaking it up after several growing cycles.

- Lighting Solutions

High efficiency LED lights will be a staple in Martian greenhouses due to the lack of reliability from sunlight on the martian surface as well as the harmful radiation effects that solar energy consequently provides. Individualized lighting systems allow for each section of a greenhouse pod to be customized for the specific plants being grown. A wide variety of commercial ***grow* lights** are applicable in this scenario. Recent studies vertical farming and hydroponic research have shown that **DC Lighting** apparatuses have a higher yield percentage in addition to supplying the plants with a healthier source of energy.

Technology demonstrated in vertical farms constructed by **Kalera** showcase this interaction on Earth, potentially leading to promising results on Mars. In addition to an efficient lighting system, **heating filaments** installed under the greenhouse will provide further warmth, a necessary aspect when the average temperature of Mars around the equator is 32 degrees F.

Case Studies:

- Microorganism Cultivator

The first iteration of a Microorganism Cultivator was designed in 1976 and tested in 1984. The primary function of this device was to allow multicellular plants and organisms to inoculate to the gravitational conditions in space and low-Earth-orbit (Mashinsky, p. 133). The machine's two key components consisted of an inoculator and a fixator, resulting in an IFC (Inoculation Fixation System). A striking system is fixed to a plate, when triggered, will break an ampoule containing a variable nutrient into a separate container housing water.

The design itself is elementary, however the concept of stabilizing an organism through a process that triggers on demand could serve as a necessary tool in order to supply enough nutritional value for any given section of a greenhouse. The following experiments are additional devices evaluated during the Salyut Missions that give further insight into how plants will react to changes in the quality of air, temperature, and gravity.

- Microbial Cultivator
- Vazon System
- Biogravistat Device
- Oasis 1A System

- Rodwell Experiment

The Rodwell Experiment (Hoffman, p. 4 - 50) (Image 005) is a process undertaken by NASA scientist in 2020 that takes a look at how water can be successfully harvested from the Martian Surface. A series of prototypes were developed through this process, all of which revolve around the central idea of siphoning water-ice from the ground into a cistern. The Rodwell process and ideology will be a necessary process if long-term colonization on the Martian surface is going to be considered successful.

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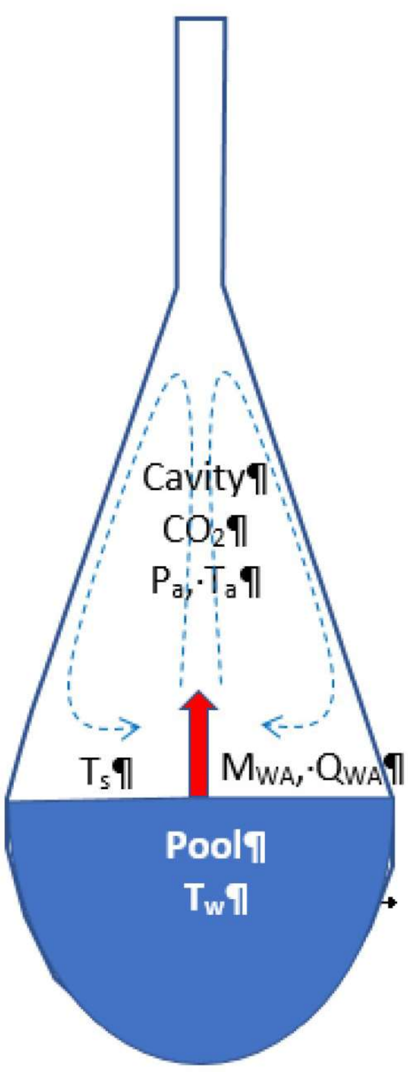
Mars Greenhouse Research

Vegetational Analysis:

- Required Diversity

- Algorithmic Studies



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Vegetational Analysis:

- Required Diversity

In order to develop an isolated sustainable living ecosystem, the **principle of required diversity** must be met and maintained (Nechitailo, p. 375). This principle takes into account the following information, and simplifies the data received into a series of plants that generate the most value for any given endeavor.

- Quality and Quantity of Vitamins, Minerals, and Biomass
- Limitations (Energy Consumption, Weight, Required Area)
- Cost (Resource and Economic)

- Algorithmic Studies

An element based algorithm combined the principle of required diversity with the daily human nutritional values (p.1), thereby producing a list of plants that have the potential to successfully grow in extreme environments such as space or Mars. The list is as follows:

- Wheat
- Rice
- Soybeans
- Peanuts
- Peas
- Beans
- Chufa
- Potatoes
- Carrots
- Radishes
- Turnips
- Beets
- Rutabagas
- Tomatoes
- Cucumbers
- Eggplants
- Kohlrabi
- White cabbage
- Cauliflower
- Brussels sprouts
- Collard greens
- Welsh onions
- Watercress
- Parsley
- Dill
- Spinach
- Salad
- Sorrel

A closer look at what data the algorithm processed will provide substantial context for why each of these plants were generated in the list of suitable organisms. Table 001 displays a sheet of quantitative and qualitative variables, with the leftmost column receiving priority in the algorithmic process. Furthermore, below is an ancillary vitamin algorithm (Mashinsky, p. 476) that helps to refine the data processed by the original element based algorithm.

(1) - The list of plants generated from the initial data input

$$R = \{r_i, iE\overline{1, n}\}$$

n = Number of Plants

(2) - The list of vitamins

$$V = \{v_j, jE\overline{1, m}\}$$

$m = m_0 + m_i$; m, a number of vitamins; m_0, a number of major vitamins; m_i, a number of representative vitamins

(3) - Set the formation + the number of plants in the set

(4) - Requirements for Mass (T_j) and Vitamins

$$T_j = j, E\overline{1, m}$$

(5) - Daily requirements for plant mass (Q_{ij})

$$Q = \{Q_i, iE\overline{1, n}\}$$

(6) - Vitamin level per 100g of plant mass

$$Y = \| y_{ij} \|$$

This data outputs a plethora of additional information regarding specific values for vitamins, minerals, plant mass, and requirements to maintain all of those levels for each of the individual plants made available in the input stage. This information can be found on page 04.

Quantitative	Qualitative	Quantitative	Qualitative
Proteins	Stability	Cellulose Transpiration	Morphology
Carbohydrates	Assimilation	Photosynthetic Output	Simplicity to Cook
Lipids	Nutritional Value	Compact Sowing	Simple to Cultivate
Vitamins	Thermal Demands	Percentage of Edible Portion	Acceptance Rate
Salts			
Productivity			
Caloric Value			

Table 001

Vegetational Analysis:

- Algorithmic Results

Table 002 is a comprehensive list of the **Biochemical Characteristics** of the plants that were found suitable to grow in extreme environments (page 03) (Mashinsky, p. 451 - 453). This data can be used to narrow down the specific function of each individual plant, thereby allowing for the introduction of a large scale plan for a greenhouse design. Variables such as how much space, energy, and water each crop needs to grow can be categorically assigned to a specific zone in order to maximize efficiency.

Plant	Group	Proteins	Lipids	Carbohydrates	Vitamins	Minerals
			Units in Grams			
Wheat	Cereals	12.0	1.70	68.70	6.40	0.850
Rice		7.60	1.0	75.80	2.350	0.240
Peanuts	Legumes	27.50	48.50	16.0	14.60	1.20
Soybeans		34.0	18.40	24.60	3.40	2.90
Peas		23.40	2.40	53.10	3.750	1.420
Kidney Beans		23.0	2.10	53.80	3.150	1.940
Chufa	Tubers	9.0	28.0	41.0	- -	- -
Potatoes		2.0	0.10	21.0	3.80	0.650
Sweet Potatoes		2.0	1.0	24.30	3.350	0.510
Carrots	Root Crops	1.50	0.170	8.0	10.10	0.260
Radishes		1.20	0.170	4.0	2.350	0.320
Turnips		3.30	0.170	10.0	7.350	0.420
Table Beets		2.0	0.170	10.80	4.50	0.290
Swede		2.0	0.40	11.0	1.10	0.330
Sweet Pepper	Fruit Vegetables	1.30	0.40	4.70	36.30	0.180
Tomatoes		0.60	0.40	4.20	6.60	0.230
Cucumbers		0.80	0.10	3.0	0.850	0.210
Kohlrabi	Leaves	3.0	0.30	8.30	5.80	0.50
White Cabbage		2.70	0.180	5.40	5.70	0.280
Cauliflower		2.50	0.340	4.90	12.40	0.30
Brussels Sprouts		6.90	0.460	6.70	19.40	0.530
Green Onions	Greens	3.0	0.30	7.30	6.40	0.350
Garden Cress		2.20	0.30	3.70	15.50	0.360
Parsley		3.70	0.30	8.10	26.80	1.590
Spinach		2.90	0.30	2.30	21.30	1.0
Lettuce		1.50	0.30	2.20	16.0	0.350
Sorrel		2.60	0.30	5.30	14.60	0.630

Table 002

Mars Greenhouse Research

Gravitational Effects:

- Introduction

- Germinating Capacity

Gravitational Effects:

- Introduction

Additional studies regarding how the physical composition of a plant changes in zero and low gravity environments can allow a greenhouse to have preliminary design decisions that embrace those changes over time. The following equations allow for each plant to be given a prediction with regards to the physical ramifications of a loss in gravitational pull.

- Germinating Capacity

The germinating capacity of each seed type will give a range of what size and how many seeds can be expected in future crop rotations. This figure was calculated using this formula:

$$S = A'/A \times 100\%$$

Where A is the total number of seeds, and A' is the number of sprouts from those seeds.

The gravitational force can then be calculated by using each individual seed's density.

$$F_g = \Delta d \times V \times a$$

Finally, micro-gravity that is relative to Earth's gravity is known to be a ratio of a total of superficial forces acting on the object (Mashinsky, p. 95). The equation for this ratio is as follows:

$$n = F_s / P \, [g]$$

These three equations can be used in order to predict how and in what directions different types of plants will grow in the Mars' gravitational pull (3.71 m/s ²). Research conducted on the Soyuz TM13 Mission, launched on October 2nd, 1991, gives a historical analysis of this same procedure. A histogram showing the deviation of leaves in wheat seedlings on the 18th day of growth during spaceflight compared to that of wheat seeds grown in Earth's soil can be seen in Chart 001.

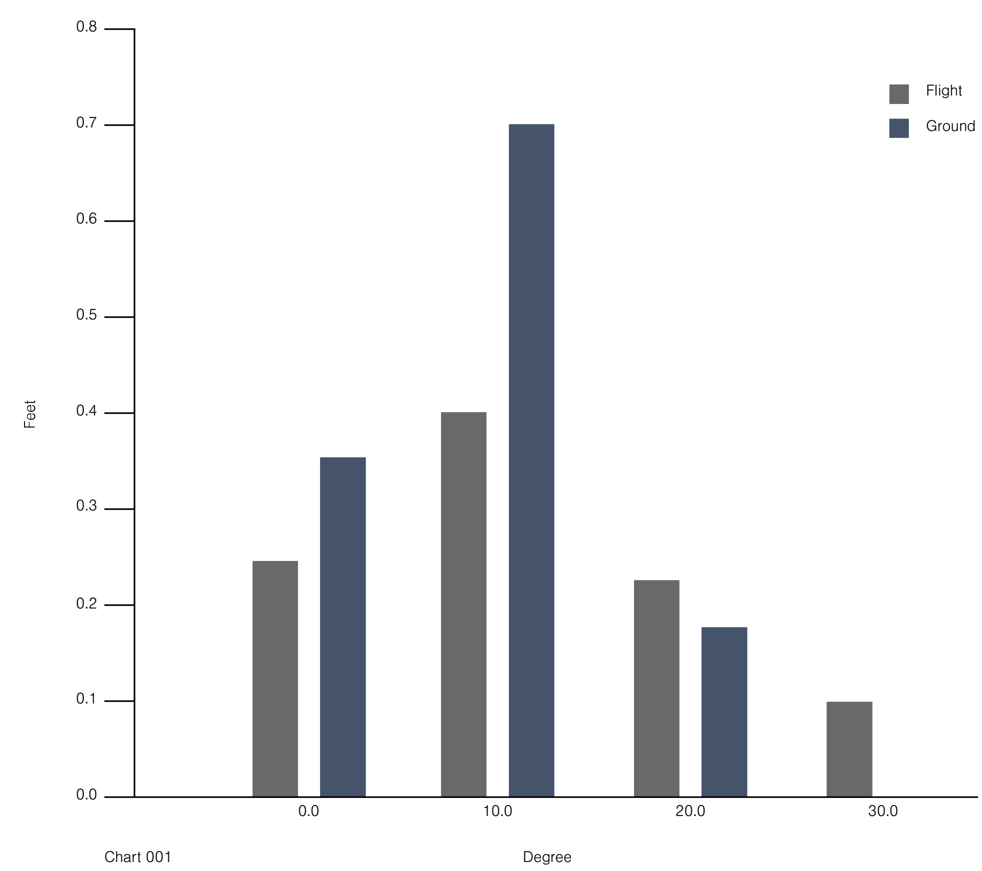

Chart 001

This information can be extrapolated in order to determine the degree of physical variations during the cultivation period of Rye on Mars (120 to 150 days), as displayed by Chart 002.

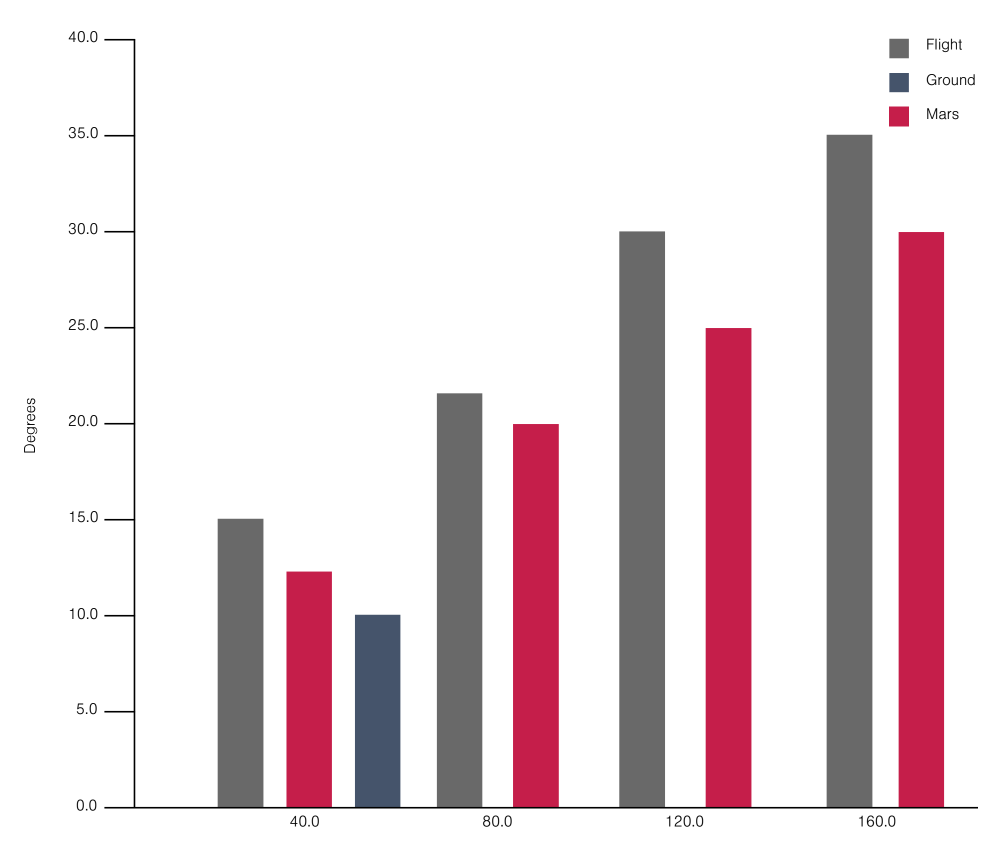

Chart 002

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Mars Greenhouse Research

Plants for Cultivation:

- Introduction
- Alfalfa
- Asteraceae
- Chives
- Cress
- Lettuce

006

007

Plants for Cultivation:

- Introduction

Utilizing the table of daily human needs (page 01), the element and vitamin based algorithms (page 02), the table of biochemical characteristics (page 03), and the gravitational predictions based on the germinating capacity equations (page 04), a complete list of plants that fulfill all of the vegetational and anthropogenic nutritional needs can be constructed.

Originally the data formulated a list of 28 plants, condensed down to 14 unique plants. An overlap of duties in terms of providing specific nutritional attributes was the leading factor in eliminating any unnecessary forms of vegetation. Below is a detailed anthology of the plants with the best percentage to survive and contribute to a sustainable colony on Mars.

- Alfalfa (Medicago sativa)

Cultivation Period: 40 days
Required Weekly Water: 5 - 10 Grams
Preferred Temperature (Survivable Temperature): 45 - 90 °F (40 - 100 °F)
Required Sunlight: 6 - 8 Hours
Preferred pH of soil (Survivable pH): 6.8 - 7.5 (6 - 8)
Preferred Density of Soil: Well drained
Spacing of rows: 18 to 24 inches apart
Proximity between Plants: 3 Feet
Growth Height: 3 Feet

Alfalfa, a flowering plant in the legume family fabaceae, is a strong *Superfood* Plant that is packed-full of vitamins and crude protein. A cool season perennial, alfalfa is extremely nutritious and is a natural source of nitrogen, making it an excellent fertilizer and consumable plant.

Overall Grade: A

- Asteraceae (Asteraceae)

Cultivation Period: 1 - 2 years
Required Weekly Water: 16.4 Grams
Preferred Temperature (Survivable Temperature): 70 ° F (40 °F)
Required Sunlight: 6 Hours
Preferred pH of soil (Survivable pH): 6.2 - 6.8 (5.5 - 7.5)
Preferred Density of Soil: Loamy
Spacing of rows: 3 Feet
Proximity between Plants: 1 - 3 Feet
Growth Height: 1 - 8 Feet

Members of the Asteraceae family have shown high levels of anti-inflammatory, antimicrobial, antioxidant and hepatoprotective traits. A flowering plant that comes in a variety of colors (purple, white, pink, red, blue, etc.), often being used as fertilizers and medicinal resources. In addition to their physical applications, the visual distinctions provided through Asteraceae's wide range of colors promotes a healthier mental environment for both plants and people.

Overall Grade: B

- Chives (Allium schoenoprasum)

Cultivation Period: 2 - 4 Weeks
Required Weekly Water: 16.4 Grams
Preferred Temperature (Survivable Temperature): 60 °F (40 - 80 °F)
Required Sunlight: 6 Hours
Preferred pH of soil (Survivable pH): 6 (5.5 - 7.5)
Preferred Density of Soil: Moist + compact
Spacing of rows: 1 Foot
Proximity between Plants: 4 - 6 inches
Growth Height: 10 - 15 inches

Chives, a flowering plant under the onion family, provide several unique flavonoid anti-oxidants as well as plant fibers/minerals. These aspects have given chives an herbal identity, as they are a way to naturally detoxify the body, thereby improving bowel movements, lowering the risk of cancer, and boosting bone/vision health.

Overall Grade: B

- Cress (Lepidium sativum)

Cultivation Period: 15 - 20 Days
Required Weekly Water: 41.83 Grams
Preferred Temperature (Survivable Temperature): 55°F (45 - 75°F)
Required Sunlight: 4 Hours
Preferred pH of soil (Survivable pH): 6 - 6.8 (5.5 - 7.5)
Preferred Density of Soil: Fine
Spacing of rows: 6 Inches
Proximity between Plants: 6 Inches
Growth Height: 6 Inches

Cress, a fast growing edible herb, is a powerhouse plant providing 2% of a human's daily nutritional value for every 100 grams consumed. In addition to this, cress contains linoleic and arachidic fat, two components that have shown to boost memory retention as well as brain activity. High levels of Calcium, Vitamin A and C, and Iron are also positive side effects of this plant.

Overall Grade: B

- Lettuce (Lactuca sativa)

Cultivation Period: 6 - 8 Weeks
Required Weekly Water: 32.8 Grams
Preferred Temperature (Survivable Temperature): 65 ° F (40 - 85 °F)
Required Sunlight: 6 - 8 Hours
Preferred pH of soil (Survivable pH): 7 (6 - 8)
Preferred Density of Soil: Well Drained
Spacing of rows: 12 to 18 inches
Proximity between Plants: 12 inches
Growth Height: 20 Inches

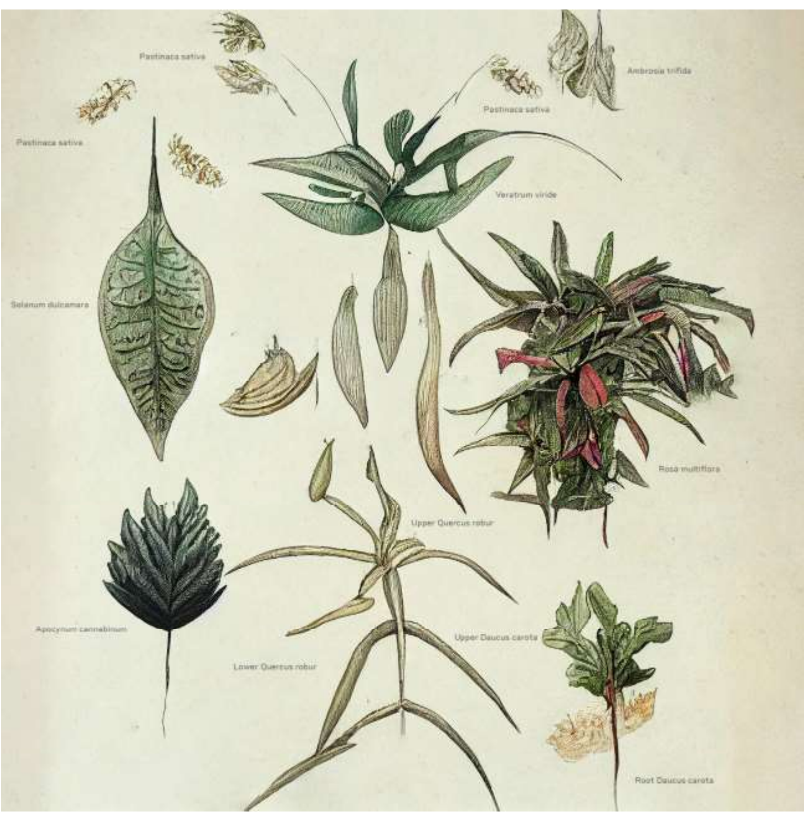
Lettuce, a leaf vegetable under the asteraceae family, has a series of nutritional benefits. In a Martian environment, the important properties of lettuce will be utilized for plants, as well as psychological benefits. Lettuce has one of the largest surface areas of leaves for a consumable produce, making it incredibly efficient in terms of CO_2 consumption and Oxygen distribution. Additionally, colonists will be very familiar with lettuce, allowing it to act as a comfort food.

Overall Grade: B

Mars Greenhouse Research

Plants for Cultivation:

- Lupinus lepidus
- Potatoes
- Quinoa
- Radish
- Rye



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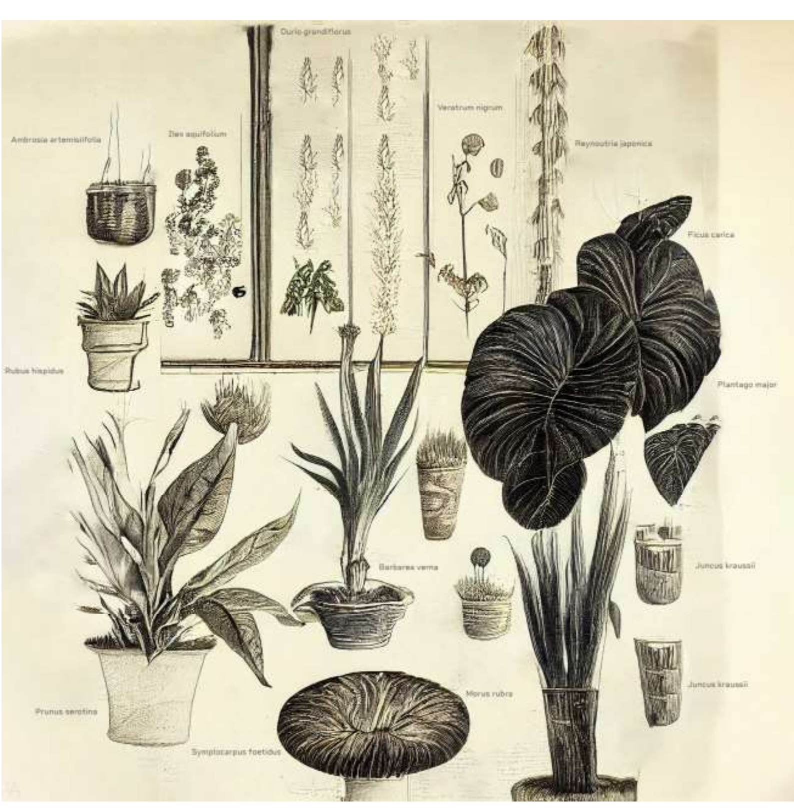

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Plants for Cultivation:

- Lupinus lepidus (Lupinus lepidus)

Cultivation Period: 1 Week
Required Weekly Water: 16.4 Grams
Preferred Temperature (Survivable Temperature): 72 °F (55 - 85 °F)
Required Sunlight: 6 Hours
Preferred pH of soil (Survivable pH): 6 (5.5 - 7)
Preferred Density of Soil: Sandy and Well Drained
Spacing of rows: 3 Feet
Proximity between Plants: 2 - 3 Feet
Growth Height: 3 to 4 feet

Lupinus lepidus, a lupine flower in the fabaceae family, offers high levels of the following nutrients: Thiamine, riboflavin, vitamin C, calcium, potassium, phosphorus, magnesium, and zinc. A leguminous plant, produced in a variety of colors, lupinus lepidus is often used as a *Green Manure*, effectively supplying the soil with additional levels of Oxygen, a considerable boost to the health of nearby plants. This process is accomplished through the aeration of Lupinus lepidus' deep tap-roots.

Overall Grade: A

- Potatoes (Solanum tuberosum)

Cultivation Period: 4 Months
Required Weekly Water: 1 - 2 Inches
Preferred Temperature (Survivable Temperature): 60 - 70°F (45 - 85°F)
Required Sunlight: 7 - 8 Hours
Preferred pH of soil (Survivable pH): 6 (5 -6.5)
Preferred Density of Soil: Well Drained
Spacing of rows: 1 Foot
Proximity between Plants: 1 Foot
Growth Height: 40 Inches

Potatoes, a starchy vegetable, will be a primary comfort food and carb-heavy fresh food. Compound nutrients and anti-oxidants are additional benefits that can be expected from these plants.

Overall Grade: C

- Quinoa (Chenopodium quinoa)

Cultivation Period: 3 - 4 Months
Required Weekly Water: 26.24 Grams
Preferred Temperature (Survivable Temperature): 60 - 75 ° F (25 - 90 °F)
Required Sunlight: 8 Hours
Preferred pH of soil (Survivable pH): 6 - 7.5 (5.5 - 8)
Preferred Density of Soil: Sandy-Loam
Spacing of rows: 1 Foot
Proximity between Plants: 8 - 10 Inches
Growth Height: 6 Feet

Quinoa, a herbaceous annual plant and member of the goosefoot family, is primarily harvested for the plant's seeds. Each of these seeds are high in protein and amino acids, along with multiple vitamins and antioxidants. Easy to harvest and cook, quinoa seeds are an excellent way to boost protein levels.

Overall Grade: B

- Radish (Raphanus sativus)

Cultivation Period: 30 days
Required Weekly Water: 16.4 Grams
Preferred Temperature (Survivable Temperature): 65 - 75 °F (40 - 90 °F)
Required Sunlight: 6 Hours
Preferred pH of soil (Survivable pH): 6 - 6.8 (5.5 - 7.5)
Preferred Density of Soil: Fine soil to a tilth
Spacing of rows: 12 Inches
Proximity between Plants: 1 - 2 Inches
Growth Height: 4 - 14 Inches

Radishes, a root vegetable of the family Brassicaceae, are a cold weather plant that excels at transferring iron levels to prevent fatigue. Their high levels phosphorus act as a bodily cleanser, cycling out different nutrients from the human bowel system. Additionally, side effects include a reduced risk of cancer, decreased kidney problems, and lower oxidative stress.

Overall Grade: C

- Rye (Secale cereale)

Cultivation Period: 120 - 150 Days
Required Weekly Water: 20.5 Grams
Preferred Temperature (Survivable Temperature): 60 - 75°F (34 - 80°F)
Required Sunlight: 4 - 6 Hours
Preferred pH of soil (Survivable pH): 5 - 7 (4.5 - 8)
Preferred Density of Soil: Sandy or Heavy Clay and poorly drained
Spacing of rows: 1 Foot
Proximity between Plants: 3 Inches
Growth Height: 1 - 2 Feet tall in bunches

Rye, a cereal grass in the Poaceae family, is very tolerant of low fertility levels and can grow in cold conditions, making it flexible and easy to successfully cultivate. The main crop for a source of grain, Rye could be seen as one of the more important plants in a foreign environment, as it will provide colonists with the ability to make foods they are comfortable and familiar with. In addition to the psychological benefits, Rye also helps to prevent cancer, heart disease, inflammation, diabetes, and bolsters menstrual health.

Overall Grade: A

Mars Greenhouse Research

Plants for Cultivation:

- Soybeans

- Tomato

- Turnips

Culinary Uses:

- Recipes

Plants for Cultivation:

- Soybeans (Glycine max)

Cultivation Period: 2 - 3 Months
Required Weekly Water: 131.2 Grams
Preferred Temperature (Survivable Temperature): 60°F (45 - 80°F)
Required Sunlight: 8 Hours
Preferred pH of soil (Survivable pH): 6 - 6.8 (5.5 to 7.5)
Preferred Density of Soil: Mulched
Spacing of rows: 30 Inches
Proximity between Plants: 3 Inches
Growth Height: 12 - 36 Inches

Soybeans, an annual legume of the Fabaceae pea family, are the richest plant source for protein due to their high levels of macro-nutrients. In addition to providing the most efficient ratio of protein to plant size, soybeans include a high level of B-vitamins, niacin, pyridoxine, and folacin. Positive side-effects of soybeans are as follows: Heart attack prevention, reduced risk of cancer, improved digestive system, lower risk of Osteoporosis, and improved circulation and oxygenation.

Overall Grade: A

- Tomato (Solanum lycopersicum)

Cultivation Period: 20 - 30 Days
Required Weekly Water: 16.4 - 32.8 Grams
Preferred Temperature (Survivable Temperature):
Required Sunlight: 7 - 8 Hours Daily
Preferred pH of soil (Survivable pH): 6.2 - 6.8 (5.5 - 7.5)
Preferred Density of Soil: Well drained
Spacing of rows: 2 Feet
Proximity between Plants: 18 - 24 Inches
Growth Height: 4 - 8 Feet

Tomatoes, a flowering plant of the nightshade family, have lycopenes which are a form of antioxidants, giving tomatoes their red color. A strong antioxidant paired with several other natural ways to help prevent cancer and guard the skin makes tomatoes an ideal plant that colonists will be familiar with.

Overall Grade: C

- Turnips (Brassica rapa rapa)

Cultivation Period: 30 - 60 Days
Required Weekly Water: 16.4 Grams
Preferred Temperature (Survivable Temperature): 40 to 75°F (34 - 80°F)
Required Sunlight: 6 Hours
Preferred pH of soil (Survivable pH): 6 - 6.5 (5.5 - 7)
Preferred Density of Soil: Loose
Spacing of rows: 12 Inches
Proximity between Plants: 1 Inch
Growth Height: 18 Inches

Turnips, a root vegetable in the brassicaceae family, are considered to be a storehouse for many different types of nutrients, with high levels of potassium and fiber. Low in calories and high in vitamin C, turnips also add a bitter portion to the generally bland pallet of a colony.

Overall Grade: B

Culinary Uses:

Each of the plants selected can be harvested and consumed by themselves, however, designing a collection of foods that work well with each other in order to prepare a series of meals enriches the experience of growing and eating. Below is a sample of some of the dishes that could be constructed using the 14 super-foods listed above.

- Rustic Root Vegetable Mash Potatoes
- Veggie Tanzia
- Tomato Quinoa Salad with Radishes
- Quinoa Salad
- Chive Bagels
- Chive Smashed-Potatoes

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Vegetational Analysis II:

Vegetational Analysis II:

Ten of the thirteen selected plants were chosen primarily for their nutritional benefits with regards to the crew members. The other three, Lupinus lepidus, Alfalfa, and Asteraceae, were chosen for their psychological and fertilization effects in the greenhouse. Table 003 - 006 display each of the ten plant's benefits in relation to the core micro-nutrients that humans need to survive. All of the information below is based off of data extracted from 100 grams of each plant, humans need about 1,300 grams of biomass a day (P1. Daily Human Nutritional Values).

Micro-nutrient	Daily Percent Values
Fat	70.0 g
Carbohydrates	400.0 g
Protein	55.0 g
Vitamin A	5,003 amu
Vitamin B	2.5 mg
Vitamin C	60.52 mg
Magnesium	420.0 mg
Calcium	1,022 mg
Iron	20.0 mg
Potassium	3,700 mg
Fiber	25.0 g
Sodium	2,800 mg
Calories	2,000

Table 003

Plant	Fat	Carbs	Protein	Vitamin A	Vitamin B	Vitamin C
			Per 100 Grams			
Chives	.70 g	4.0 g	3.30 g	43 amu	0.10 mg	58.1 mg
Cress	4.30 g	7.20 g	3.2 g	173 amu	- -	34.50 mg
Lettuce	- -	3.0 g	1.40 g	7,405 amu	0.10 mg	9.20 mg
Potatoes	7.60 g	11.0 g	5.10 g	- -	0.20 mg	9.90 mg
Quinoa	- -	69.0 g	10.30 g	- -	- -	- -
Radish	.20 g	7.0 g	0.90 g	- -	5.0 mg	18.80 mg
Rye	3.40 g	48.0 g	8.40 g	- -	- -	- -
Soybeans	9.0 g	8.0 g	18.20 g	- -	0.20 mg	1.70 mg
Tomatoes	- -	5.40 g	0.950 g	400 amu	- -	7.80 mg
Turnips	- -	10.20 g	0.950 g	100 amu	- -	7.80 mg

Table 004

Plant	Calories
	Per 100 Grams
Chives	30
Cress	40
Lettuce	15
Potatoes	132
Quinoa	190
Radish	30
Rye	260
Soybeans	172
Tomatoes	27
Turnips	57

Table 005

Plant	Magnesium	Calcium	Iron	Potassium	Fiber	Sodium
			Per 100 Grams			
Chives	42.0 Mg	92.0 mg	- -	- -	2.5 g	- -
Cress	- -	40.5 mg	- -	- -	1.20 g	- -
Lettuce	13.0 mg	36.0 mg	- -	- -	1.34 g	28.0 mg
Potatoes	20.0 mg	119.0 mg	0.60 mg	396.0 mg	1.80 g	433.0 mg
Quinoa	- -	20.0 mg	3.80 mg	- -	3.0 g	- -
Radish	10.0 mg	18.0 mg	0.20 mg	216.0 mg	1.8 g	- -
Rye	- -	- -	3.0 g	- -	6.80 g	- -
Soybeans	86.0 mg	102.0 mg	5.10 mg	515.0 mg	6.0 g	- -
Tomatoes	- -	36.0 mg	0.950 mg	221.0 mg	1.0 g	287.0 mg
Turnips	- -	36.0 mg	0.60 mg	- -	2.0 g	221.0 mg

Table 006

Mars Greenhouse Research

Vegetational Analysis II:

Vegetational Analysis II:

Chart 003 is a visual representation of the information displayed in Table 003 - 006. All of the data is calculated through 100 gram samples from each of the selected plants. Each of plants' contributions to a crew member's daily nutritional intake is illustrated through a series of pie charts on the following page.

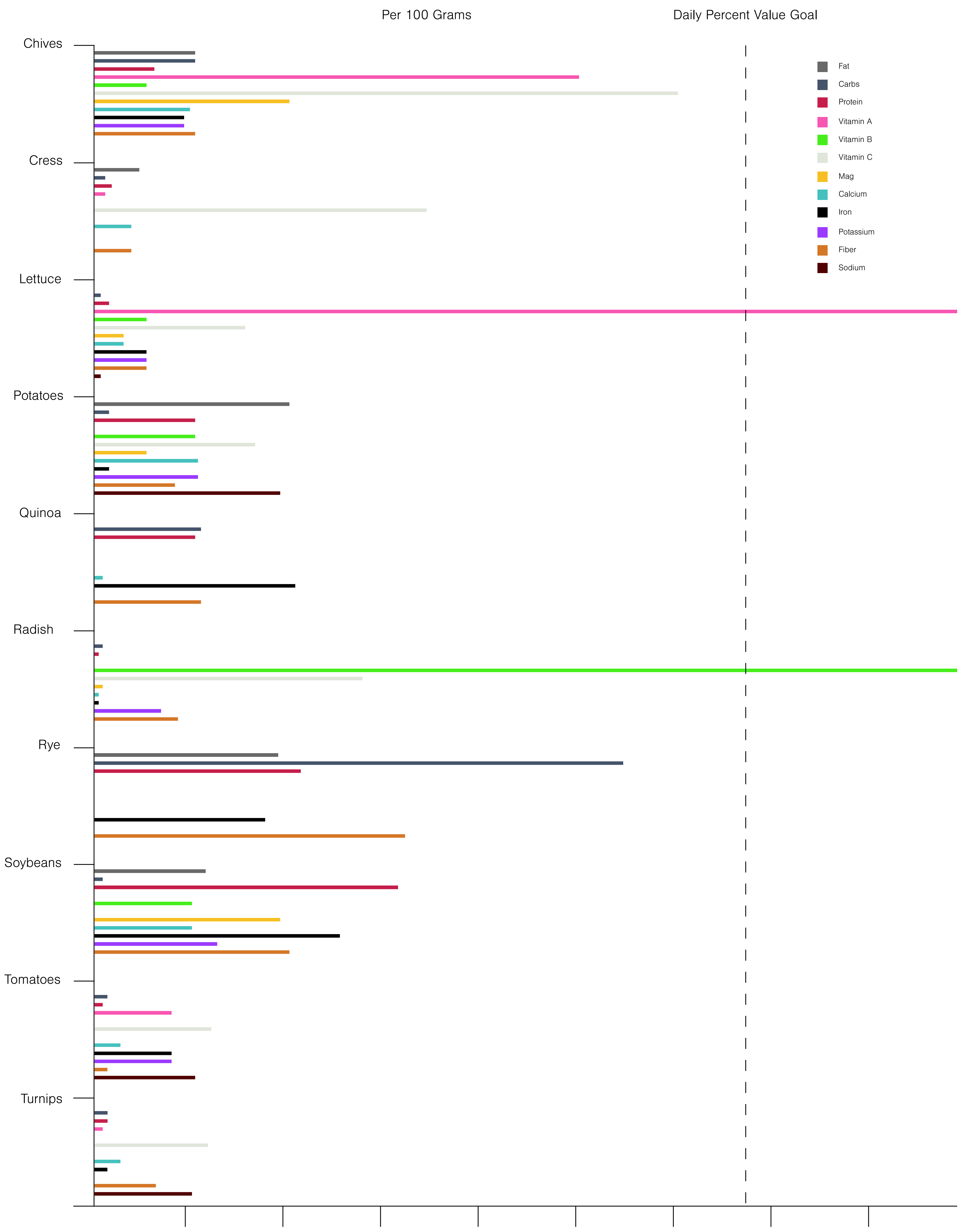

Chart 003

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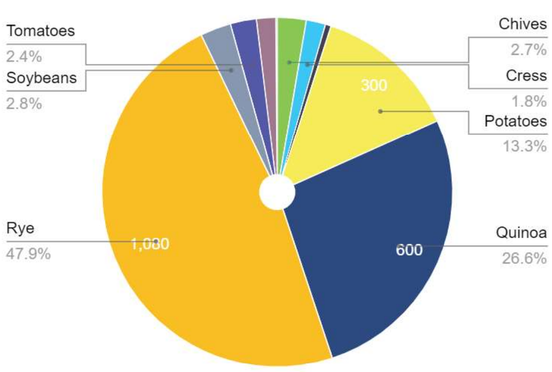
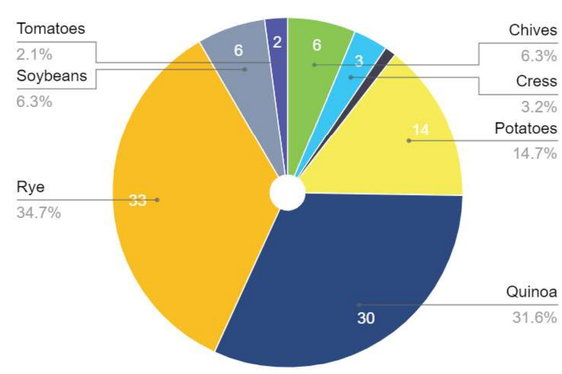
Cultivation Output:

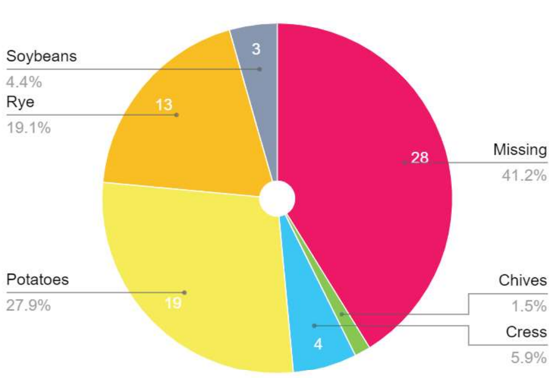
Daily Percent Values: Calories



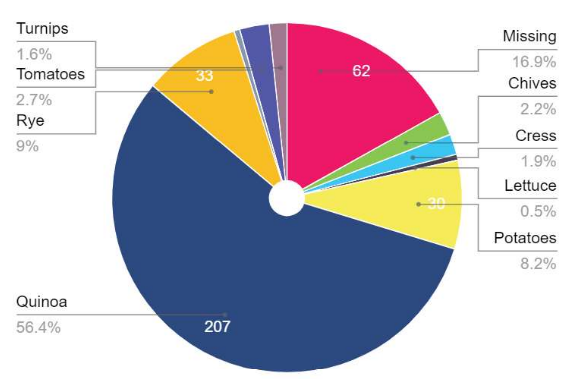
Daily Percent Values: Protein (Grams)



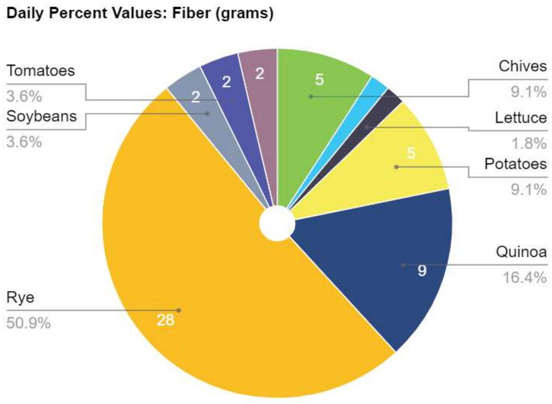
Daily Percent Values: Fat (Grams)



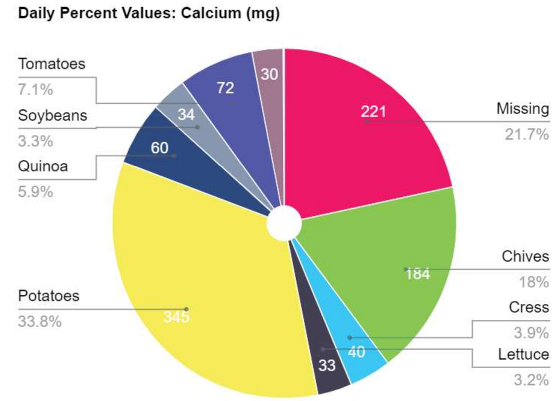
Daily Percent Values: Carbohydrates (Grams)



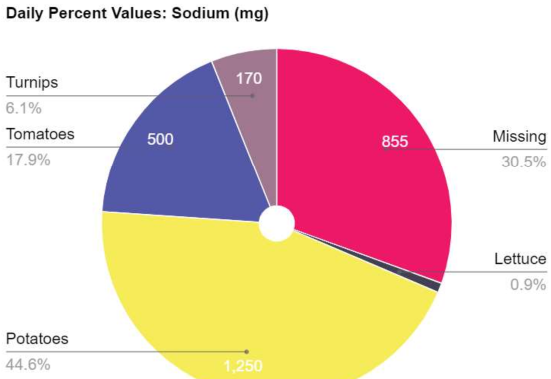
Daily Percent Values: Fiber (grams)



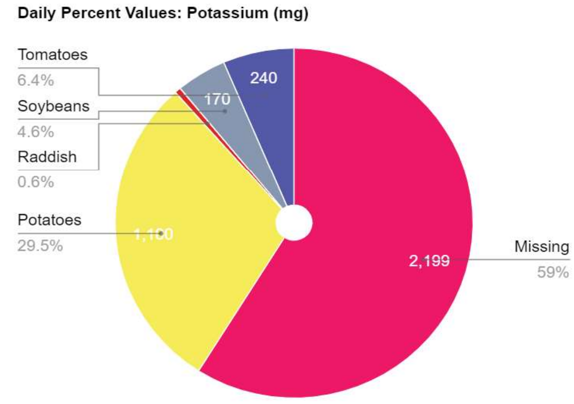
Daily Percent Values: Calcium (mg)



Daily Percent Values: Sodium (mg)



Daily Percent Values: Potassium (mg)



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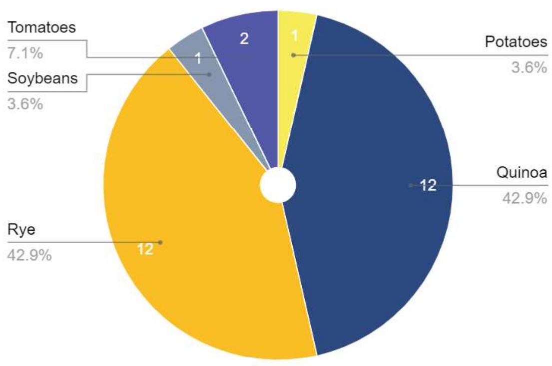
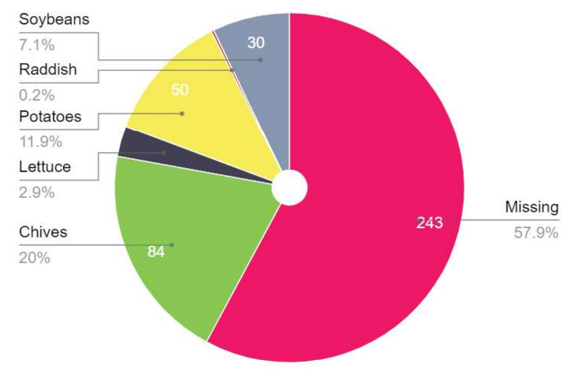
Cultivation Output:

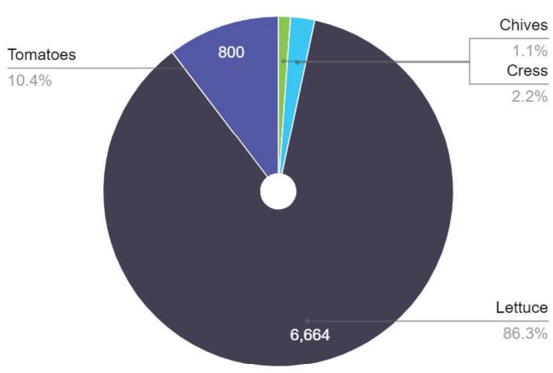
Daily Percent Values: Iron (mg)



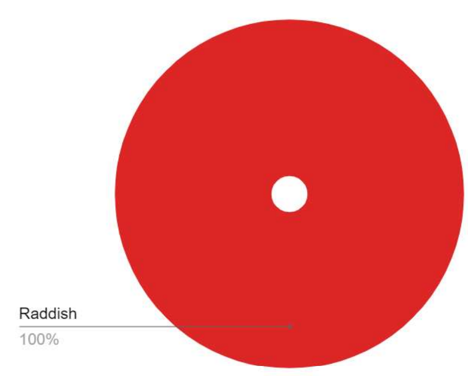
Daily Percent Values: Magnesium (mg)



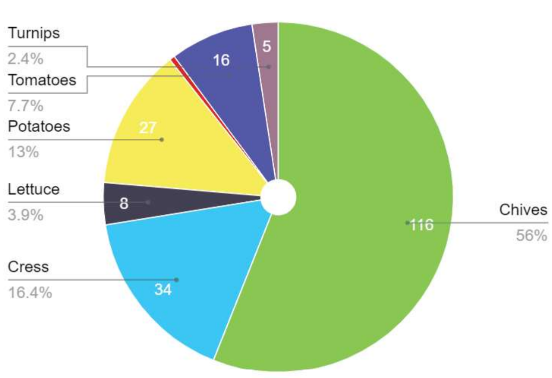
Daily Percent Values: Vitamin A (amu)



Daily Percent Values: Vitamin B (mg)



Daily Percent Values: Vitamin C (mg)



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Mars Greenhouse Research

Data Application:

- Vegetational Analysis I and II

Greenhouse Design:

- Greenhouse 01

- Greenhouse 02

- Greenhouse 03

- Cultivation Output

Table 4. VEGETABLE PRODUCTION CHART*											
Vegetable	Amount needed for one adult (fresh use)		Amount needed for a family of four (fresh use)		Amount needed for one adult (processed/storage)		Amount needed for a family of four (processed/storage)		Spacing between rows	Yield per 100 feet of row**	Yield per 100 square feet**
	Pounds	Feet of Row	Pounds	Feet of Row	Pounds	Feet of Row	Pounds	Feet of Row	Inches	Pounds	Pounds
Asparagus	1.5	10	5	35	5	35	15	100	36	15	5
Beans, Lima	3	40	10	125	3	40	10	125	21	8	5
Beans, snap	15	25	50	85	18	30	55	90	21	60	34
Beets	3.5	4	10	10	7.5	8	25	25	21	100	57
Broccoli	8	20	25	60	12	30	35	90	30	40	16
Brussels sprouts	6	20	20	65	8	25	25	85	30	30	12
Cabbage	15	13	45	40	15	13	45	40	30	120	48
Carrots	10	8	30	25	10	8	30	25	21	120	69
Cauliflower	9	10	25	30	12	15	35	40	33	90	33
Celeriac	0.5	1	2	3	--	--	--	--	21	60	34
Celery	4	1	12	3	--	--	--	--	28	430	184
Chinese cabbage	2	1	6	2	--	--	--	--	27	420	187
Collards	2	3	5	7	4	5	10	15	21	80	46
Cucumbers	8	4	25	12	10	5	30	15	48	200	50
Eggplant	4	3	10	9	--	--	--	--	30	115	46
Endive	4	7	10	18	--	--	--	--	15	55	44
Garlic	1	4	3	12	2	8	5	20	15	25	20
Jerusalem artichoke	1.5	2	5	3	1	2	3	2	48	150	38
Kale	1	1	3	3	2	2	6	6	21	100	57
Kohlrabi	1.5	2	5	7	--	--	--	--	21	75	43
Leeks	1	3	3	7	1	3	3	7	15	45	36
Lettuce	6	12	20	40	--	--	--	--	15	50	40
Muskmelon	10	9	30	27	2	3	6	6	48	110	28
Mustard	1	2	3	6	--	--	--	--	21	50	29
Okra	3	5	10	17	4	6	10	20	27	60	27
Onions (dry)	8	12	25	30	20	24	60	72	15	115	92
Onions (green)										50	40
Parsley	0.25	1	1	4	0.5	2	2	7	15	30	24
Parsnips	3	6	10	20	3	6	10	20	21	50	29
Peas, shelled	4.5	15	15	50	7.5	25	25	85	15	30	24
Peas, snap	1	3	3	8	1	3	3	8	15	40	32
Peppers	3	3	10	8	3.5	3	10	8	30	120	48
Pop corn	--	--	--	--	4	15	15	55	33	28	10
Potatoes, Irish	25	21	75	50	75	50	225	150	30	150	60
Potatoes, sweet	3	18	10	25	4	10	10	25	36	40	13
Pumpkins	10	4	30	10	8	3	25	8	60	300	60
Radishes	4	40	10	100	--	--	--	--	9	10	11
Rhubarb	4	4	10	10	4	4	10	10	48	100	25
Rutabaga	1.5	2	5	5	2	2	5	5	21	100	57
Salsify	0.5	1	2	3	0.5	1	2	3	21	80	46
Spinach	3	6	10	20	5	3	15	8	15	50	40
Squash, summer	10	5	30	12	3	2	10	4	42	240	69
Squash, winter	6	3	20	9	3	2	10	4	60	230	46
Sweet corn	25 ears	25	80 ears	80	50 ears	50	160 ears	160	30	100 ears	36 (kernels)
Swiss chard	3	4	10	12	4.5	6	15	20	21	85	49
Tomatoes	24	15	70	40	36	23	110	65	36	165	55
Turnips	5	5	15	15	7	7	20	20	21	100	57
Watermelons	12	12	35	35	--	--	--	--	72	100	17

*Assumptions per person is for individuals who like to eat that particular plant. If they don't, they won't plant any.
Amount for a family of four is generally about three times the amount needed by one adult. This is because a family of four would usually include some children who probably wouldn't eat as much as an adult, or the family might include one or more members who wouldn't care to eat that particular vegetable.

** Yields are based on standard row plantings. Wide row planting, trellising, and other intensive gardening techniques would probably yield more than the amounts listed above.

Table 007

Data Application:

- Vegetational Analysis I and II

The information gained from the Vegetational Analysis I (p. 3-4) and II (p. 9-10) can be applied to the Martian Greenhouse design in order to maximize space and provide ample space for each type of plant through designated zoning. The primary information gained from each of these studies can be simplified to the following: Growth patterns of each of the selected plants and the quantity of each plant needed to provide enough nutritional value to meet a human's daily biomass goal. Additional information regarding crop yield percentages from Michigan State University (Table 007) helped determine the output of each plant.

Greenhouse Design:

The preliminary Mars Greenhouse Research has led to understanding which plants are most fit to grow in the Martian environment, and how efficient they are in terms of producing nutrition for their limitations (energy consumption, space required, water, etc.). These studies, paired with the information gathered from Vegetational Analysis I and II, allows a diagrammatic scheme to be created with the objective of developing the overall design of each greenhouse (Image 011 - 014). Below, this information can be found in a spatial diagram of each of the four pre-fabricated greenhouses.

- Greenhouse 01 (4,080 cubic feet) (316.152 square feet of plantable area)

10 Planters (25.42 square feet, 7.86' x 3.23') + 2 Planters (30.976 square feet, 9.59' x 3.23')

Ground Floor (8 Planters, 214.472 square feet)

Potatoes: 204 square feet (18 rows)

Secondary Floor (4 Planters, 101.68 square feet)

Chives: 48 square feet (4 rows)

Lettuce: 48 square feet (4 rows)

- Greenhouse 02 (Replicated Metrics of Greenhouse 01)

Ground Floor (8 Planters)

Potatoes: 120 square feet (10 rows)

Lettuce: 92 square feet (8 rows)

Secondary Floor (4 Planters)

Radish: 48 square feet (4 rows)

Turnips: 48 square feet (4 rows)

- Greenhouse 03 (Replicated Metrics of Greenhouse 01)

Ground Floor (8 Planters)

Soybeans: 106 square feet (10 rows {2 feet apart})

Secondary Floor (4 Planters)

Tomatoes: 48 square feet (4 rows {2 feet apart})

- Cultivation Output

Table 008 shows the total cultivation output of all the plants in the four pre-fabricated greenhouses. In total, the four greenhouses deployed on the surface of Mars with a crew size of seven can produce 870/1,300 grams needed to sustain an individual's personal biomass intake. For the first two years of residency, the remaining 430 grams will have to be supplemented through pre-packaged freeze-dried food.

Upon the crew developing their colony, larger and more expansive greenhouses can be constructed, allowing for the growth of more land intensive plants, such as rye and a larger supply of quinoa. This greenhouse expansion will also allow the former greenhouses to now harbor other types of plants selected for this mission such as alfalfa, asteraceae, cress, and lupinus lepidus.

Plant	Maturation Period	Pounds/ square foot	Designated Space	Daily Intake	Daily Crew Intake	Required Output	Actual Output
			Total Area		Crew Size of 7		
Chives	4 - 6 weeks	2.42	48 sq. ft.	200 g	1,400 g	39,200 g	52,689 g
Lettuce	6 - 8 weeks	0.5	140 sq. ft.	90 g	630 g	30,870 g	31,751 g
Potatoes	16 weeks	1.5	324 sq. ft.	275 g	1,925 g	215,600 g	220,445 g
Radish	4 weeks	0.1	48 sq. ft.	10 g	70 g	2,100 g	2,177 g
Soybeans	8 - 12 weeks	0.34	106 sq. ft.	30 g	210 g	14,700 g	16,347 g
Tomatoes	3 - 4 weeks	1.65	48 sq. ft.	200 g	1,400 g	35,000	36,287
Turnips	4 - 6 weeks	1.0	48 sq. ft.	65 g	455 g	20,475 g	21,772 g

Table 008

1 lb = 453.59237 g

Daily Crew Intake (7) (Maturation Period) = Required Output

Designated Space (Pounds/ square foot)(453.59237) = Actual Output

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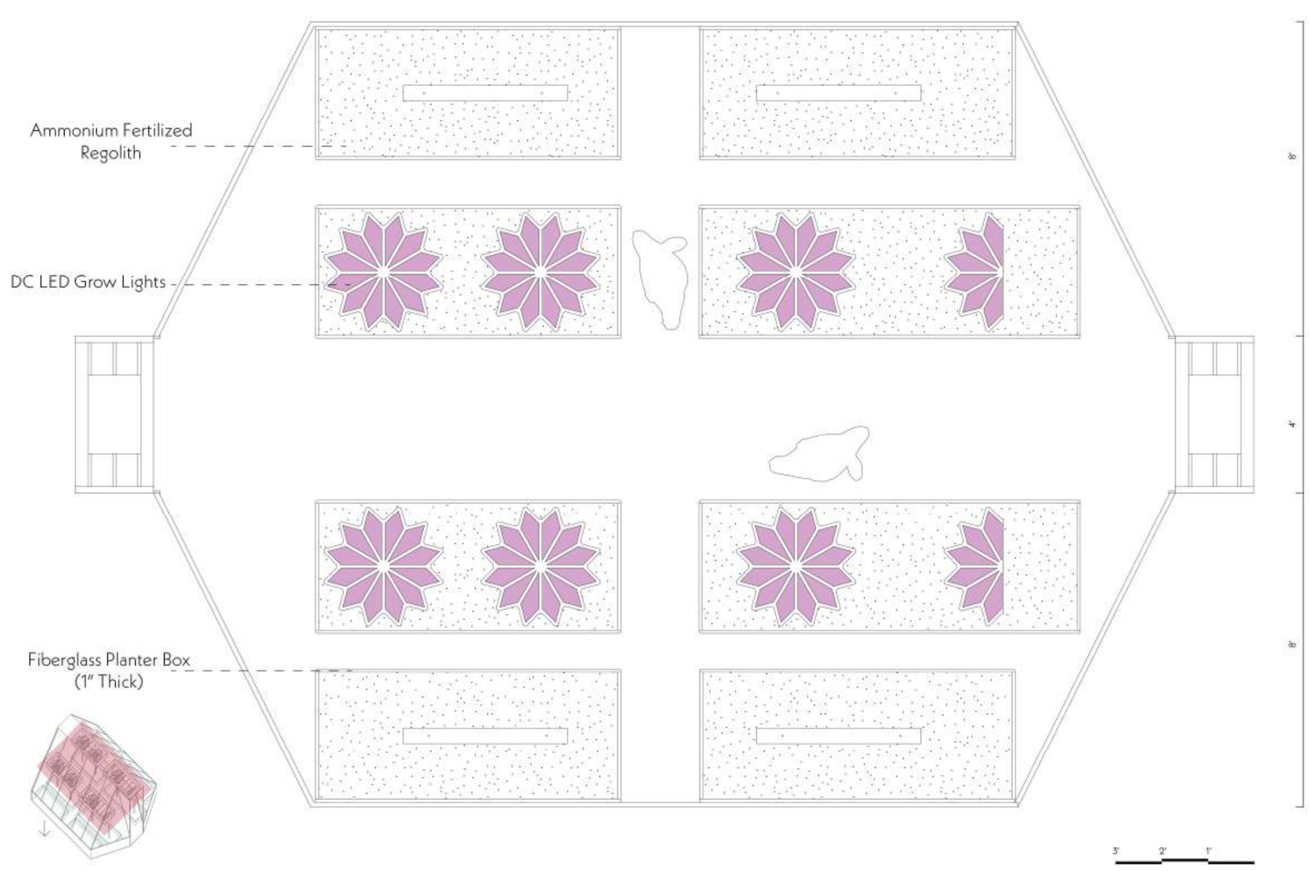
Mars Greenhouse Research

Greenhouse Design:

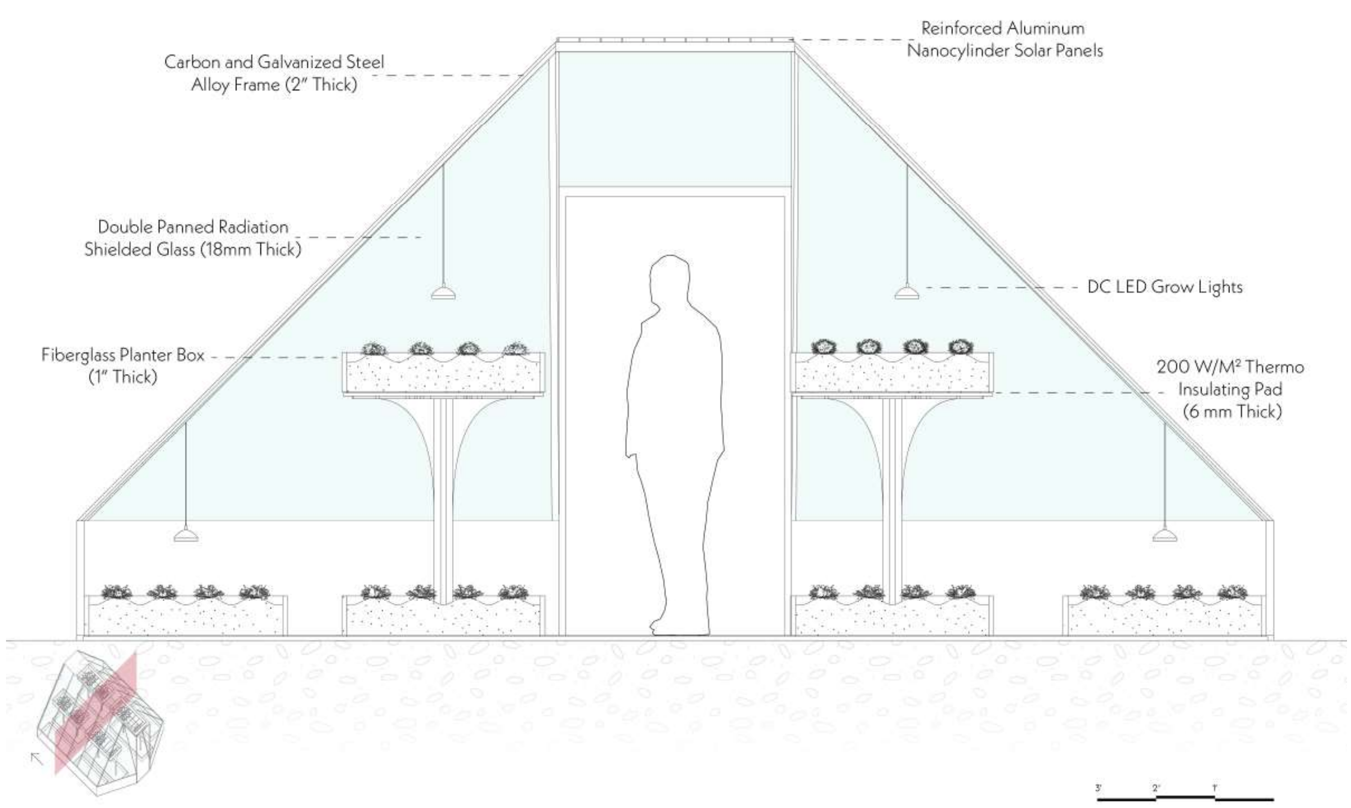
Greenhouse Design:

Greenhouse /// Plan



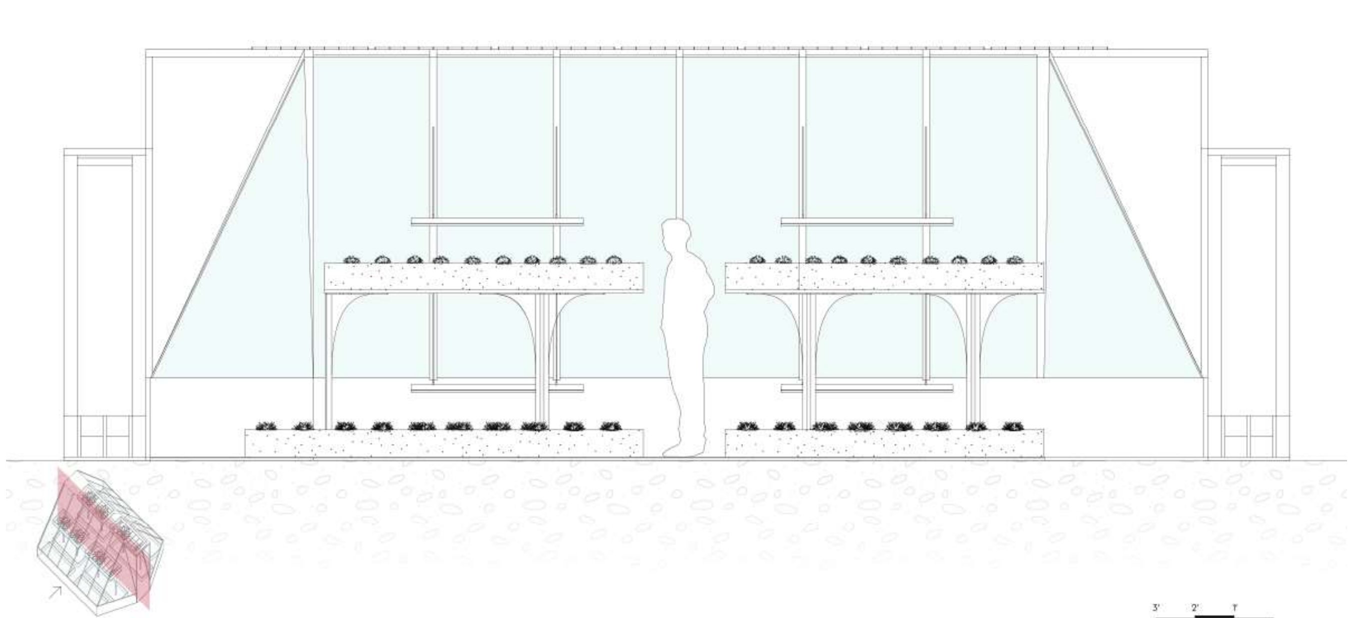
011

Greenhouse /// Transverse Section



012

Greenhouse /// Longitudinal Section



013

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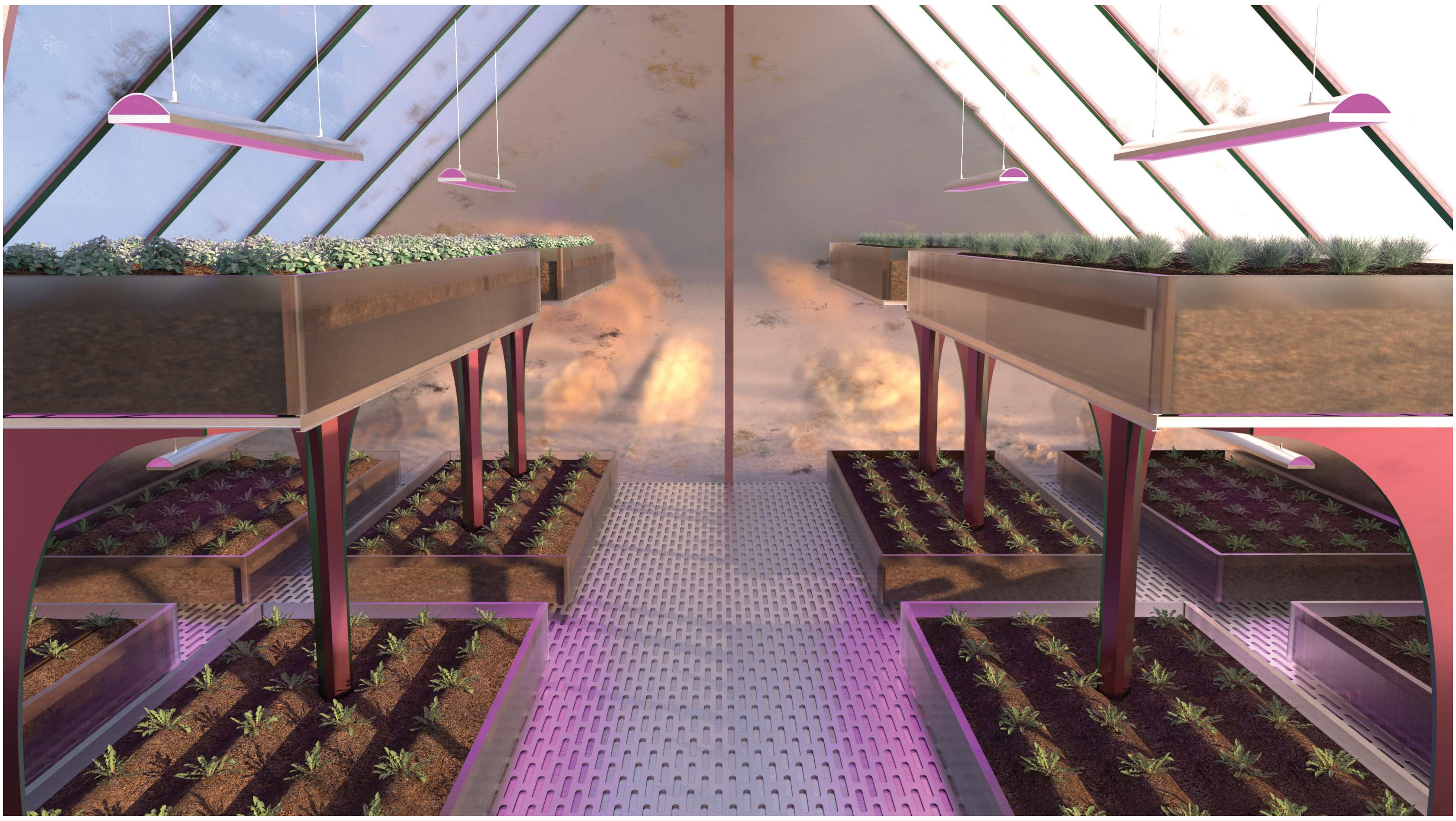
Mars Greenhouse Research

Greenhouse Design:

Greenhouse Design:

- 4,080 cubic feet
- 316.152 square feet of plantable area (12 Planters)
- 10 Planters (25.42 square feet, 7.86' x 3.23')
- 2 Planters (30.976 square feet, 9.59' x 3.23')



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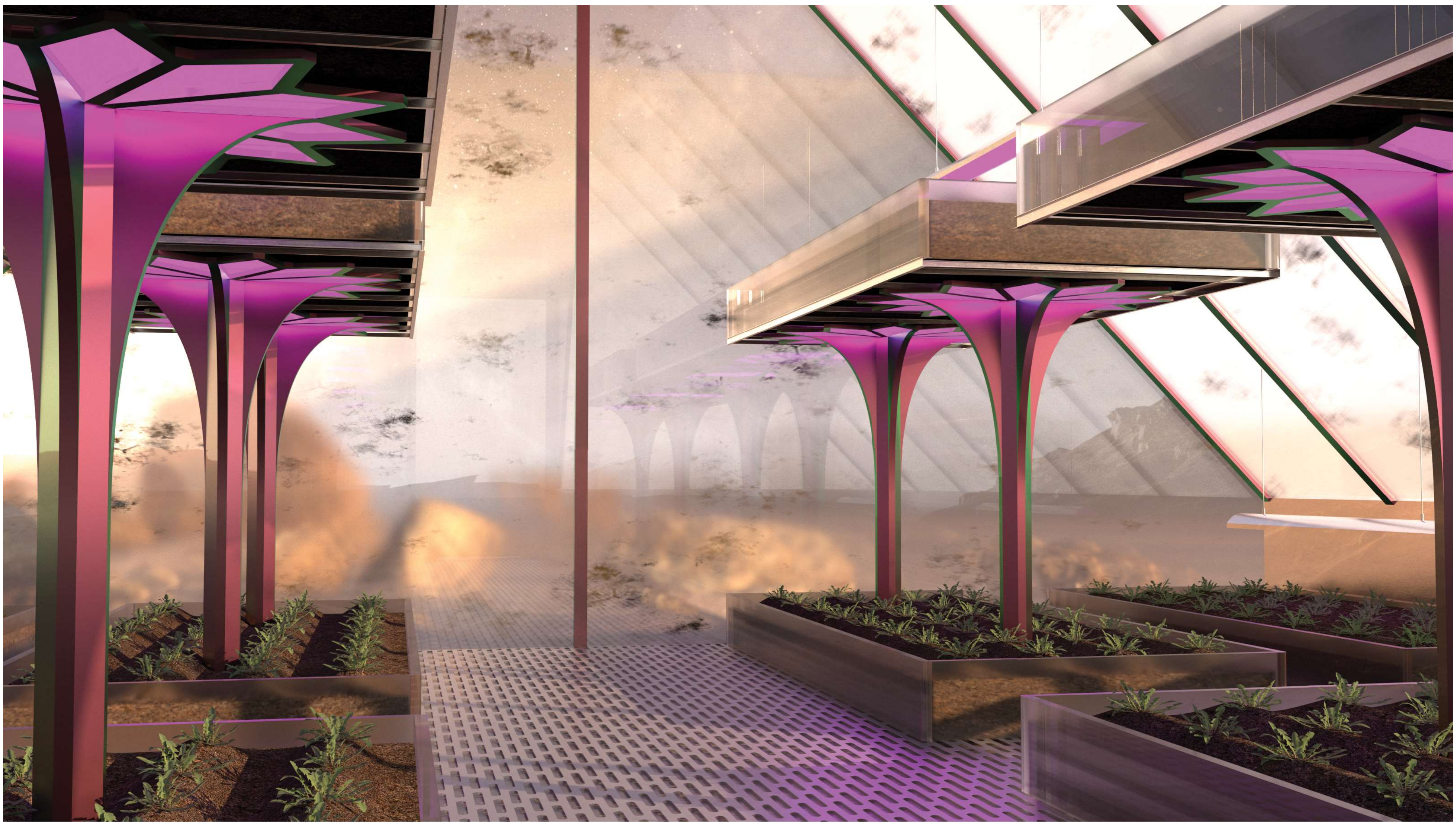

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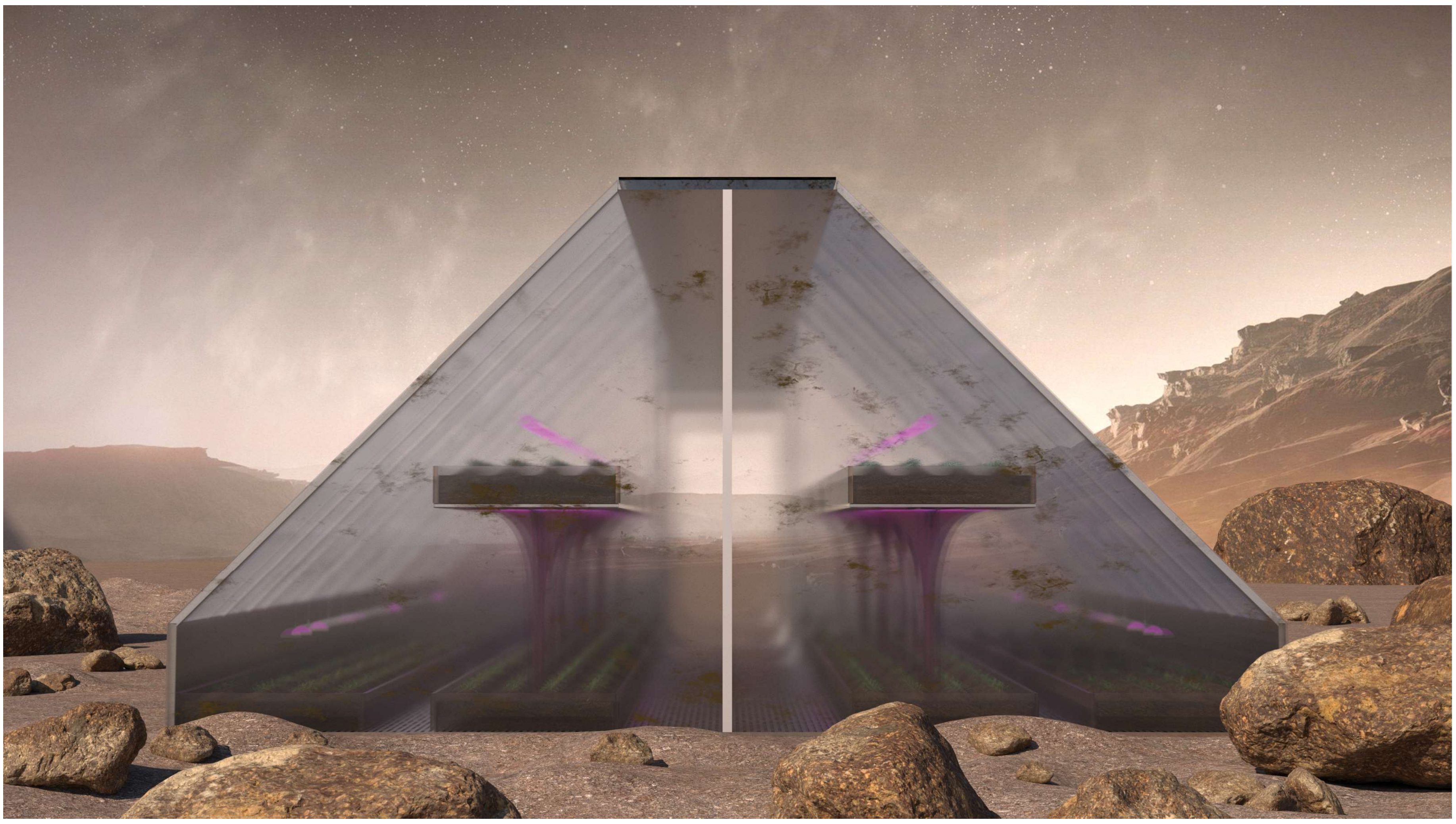
Mars Greenhouse Research

Greenhouse Design:

Greenhouse Design:

- 20 Feet Long
- 20 Feet Wide
- 10 Feet High



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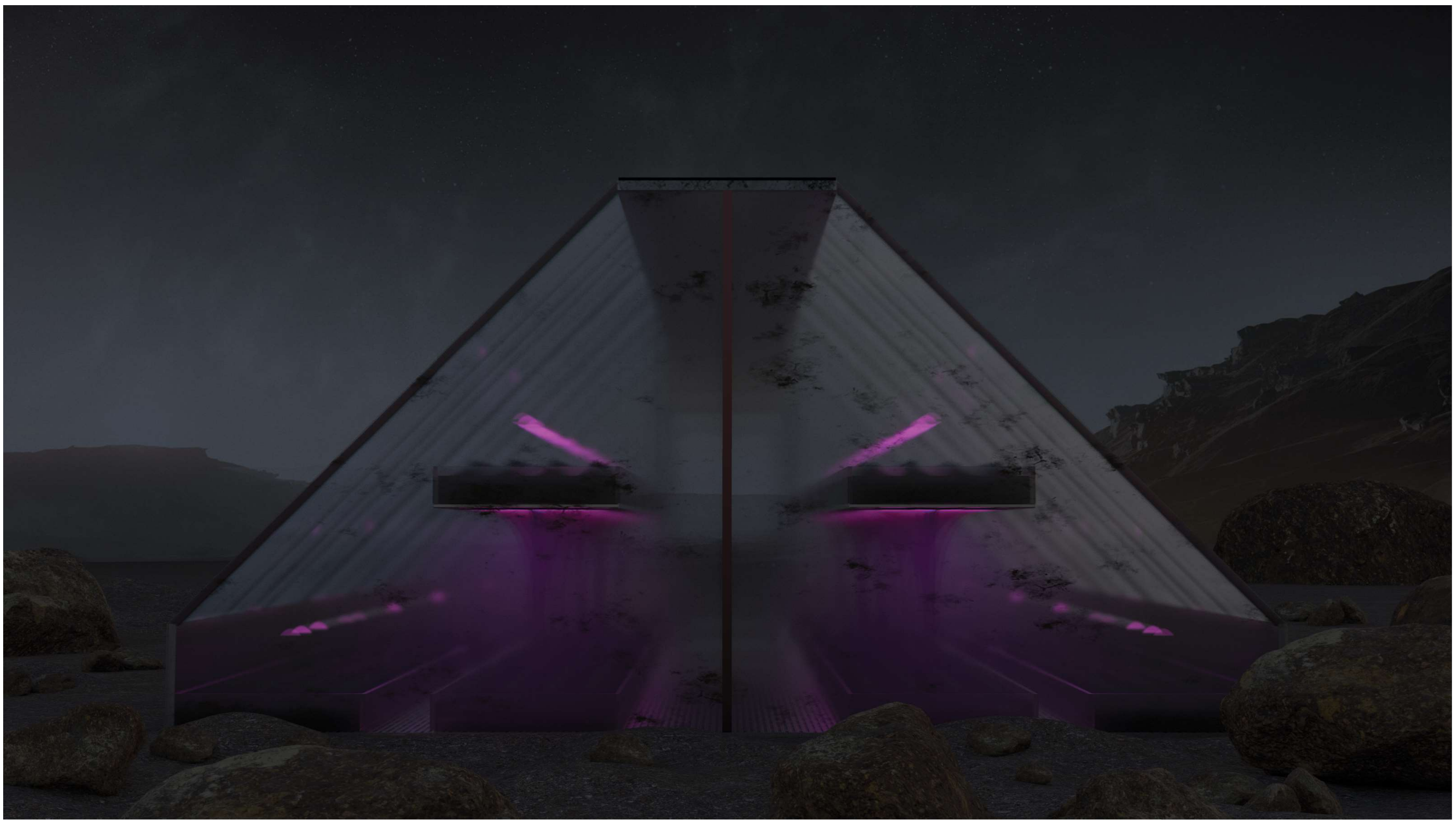


017

Logan Miller
UNIVERSITY OF HOUSTON COLLEGE OF SPACE ARCHITECTURE AND DESIGN

Mars Greenhouse Research

Packaging:

Construction:

Packaging:

Each of the Greenhouse Modules will be pre-constructed on Earth and shipped to the Martian surface in several easy-to-build components. These components will be packaged with a unique variation of polyethylene, designed to act as a binding agent for the Martian regolith during the 3D printing process. The cargo bay on-board M.A.R.S. (Martian Ascent and Reentry Ship) is designed to hold 100 tons of contents within an 8x8x8 Meter chamber. Image 018 + 019 display how the Greenhouse Module, as well as other cargo supplies, will be stored for the transit mission to Mars.

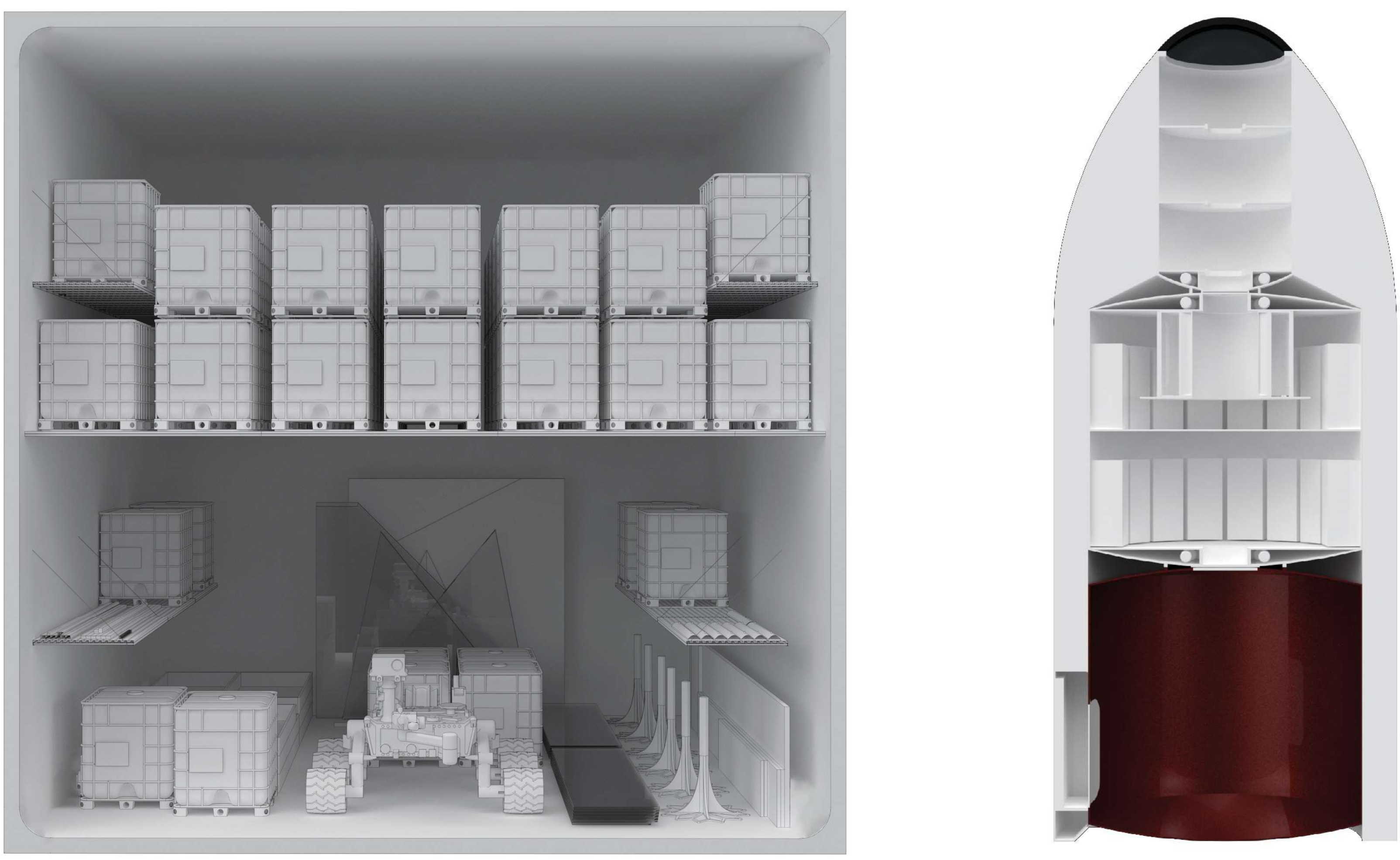
Construction:

Once the crew and Greenhouse Modules are on site, a simple construction process can take place in order to pressurize the space and begin the interior atmospheric transition. Each of the double panned radiation shielding glass pieces have been outfitted with silicon caulk to minimize the risk of external air infiltration the interior space. A series of galvanized steel screws meld the structural members to the glass panels, resulting in a finished architectural shell.

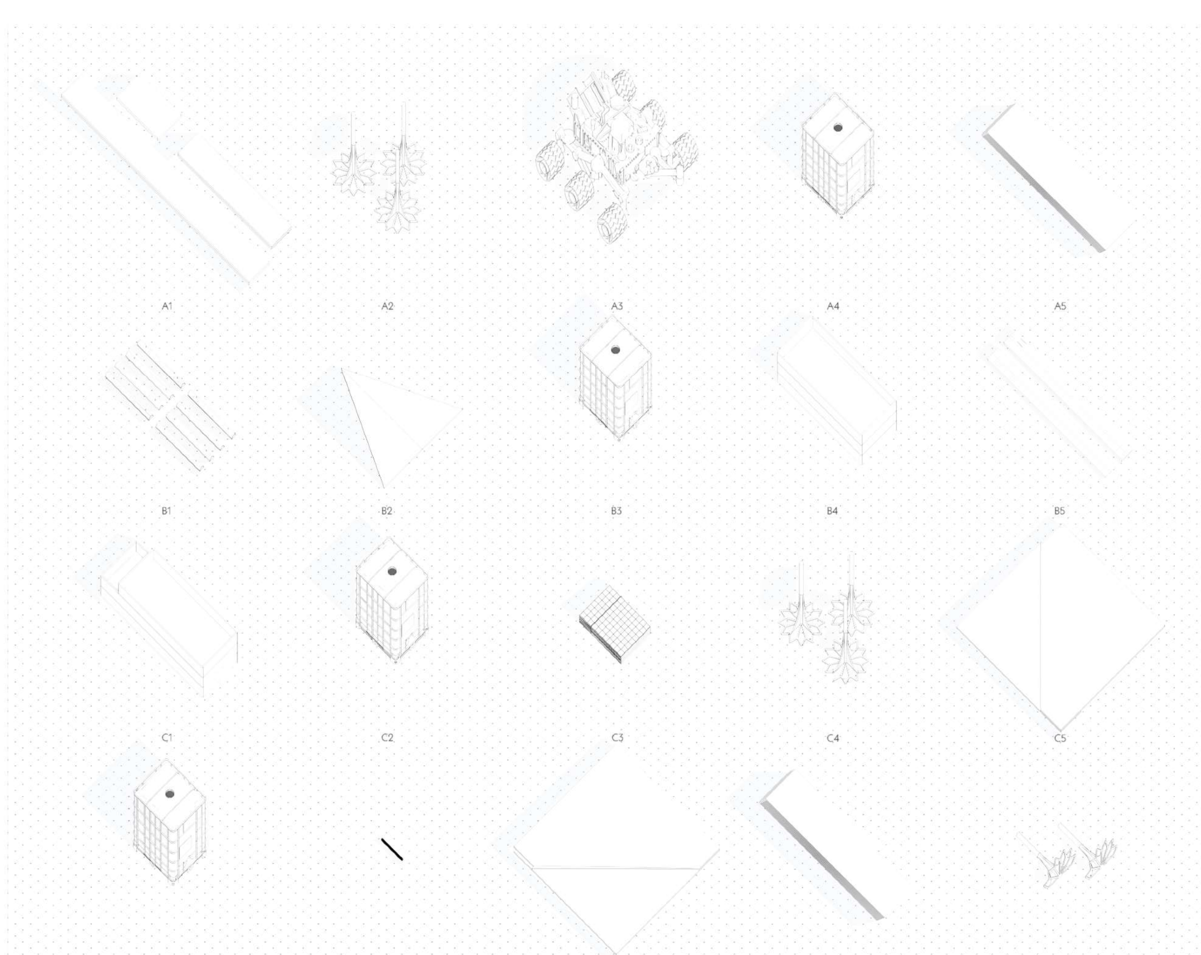
Thermo-insulating pads are then installed on top of a two-piece foundation. Electrical and plumbing follow suit, allowing for the final galvanized steel surface layer to be placed. Solar trees and secondary level supports are then installed, allowing the pre-constructed fiberglass planter boxes to be bolted into place.

Finally, solar panels and the hanging DC LED lights are incorporated into the space. Once the airlock has been applied and the interior space is pressurized and temperature controlled, fertilized soil and the first batch of seeds can be planted, thereby beginning the cultivation cycle on the Red Planet.

This process should take no more than three days per Greenhouse Module, allowing for the crew to partake in homegrown martian meals within six months of landing on the surface.



018



019

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Mars Greenhouse Research

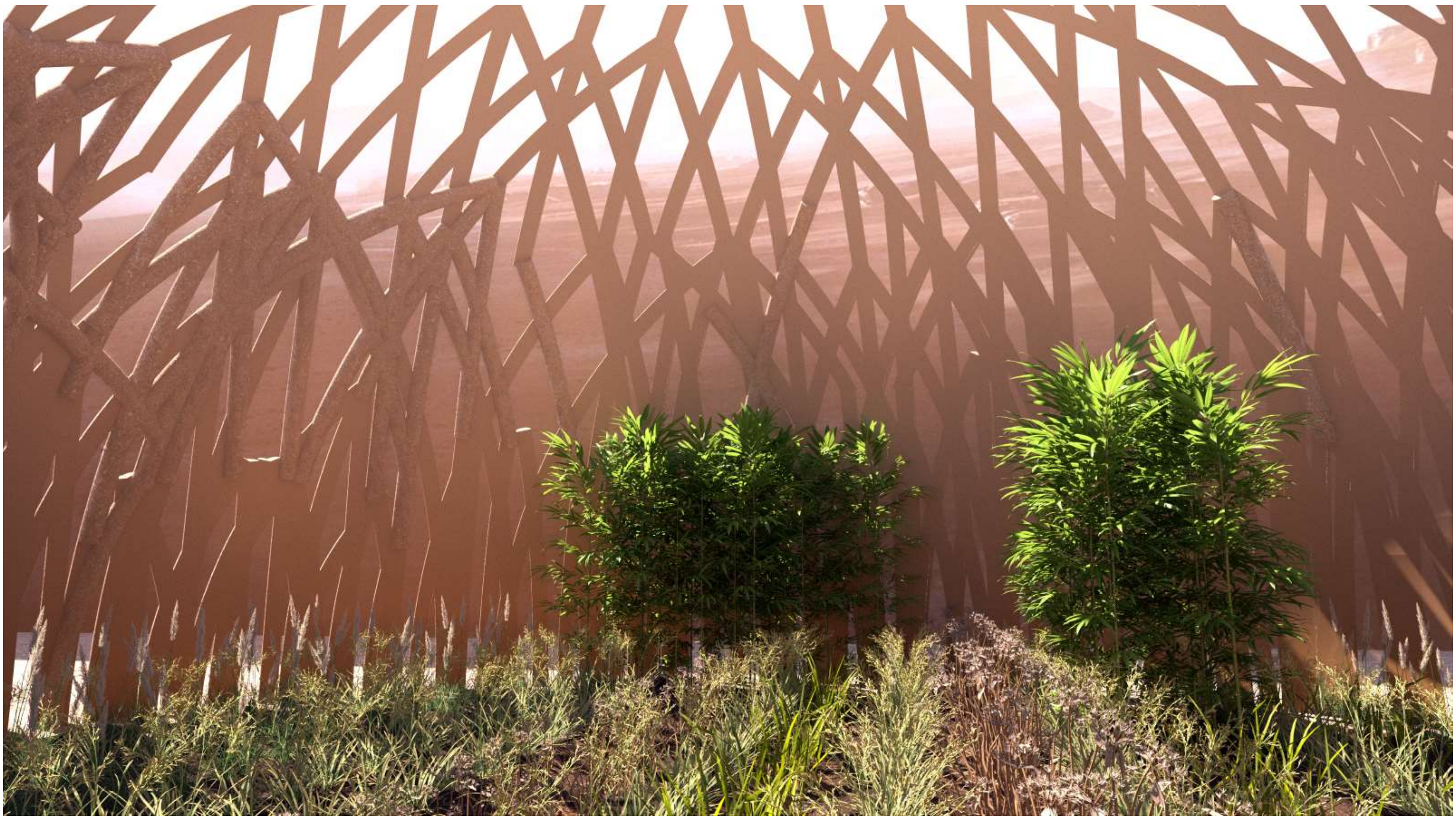
Expanded Greenhouse Design:

- Domed Greenhouses

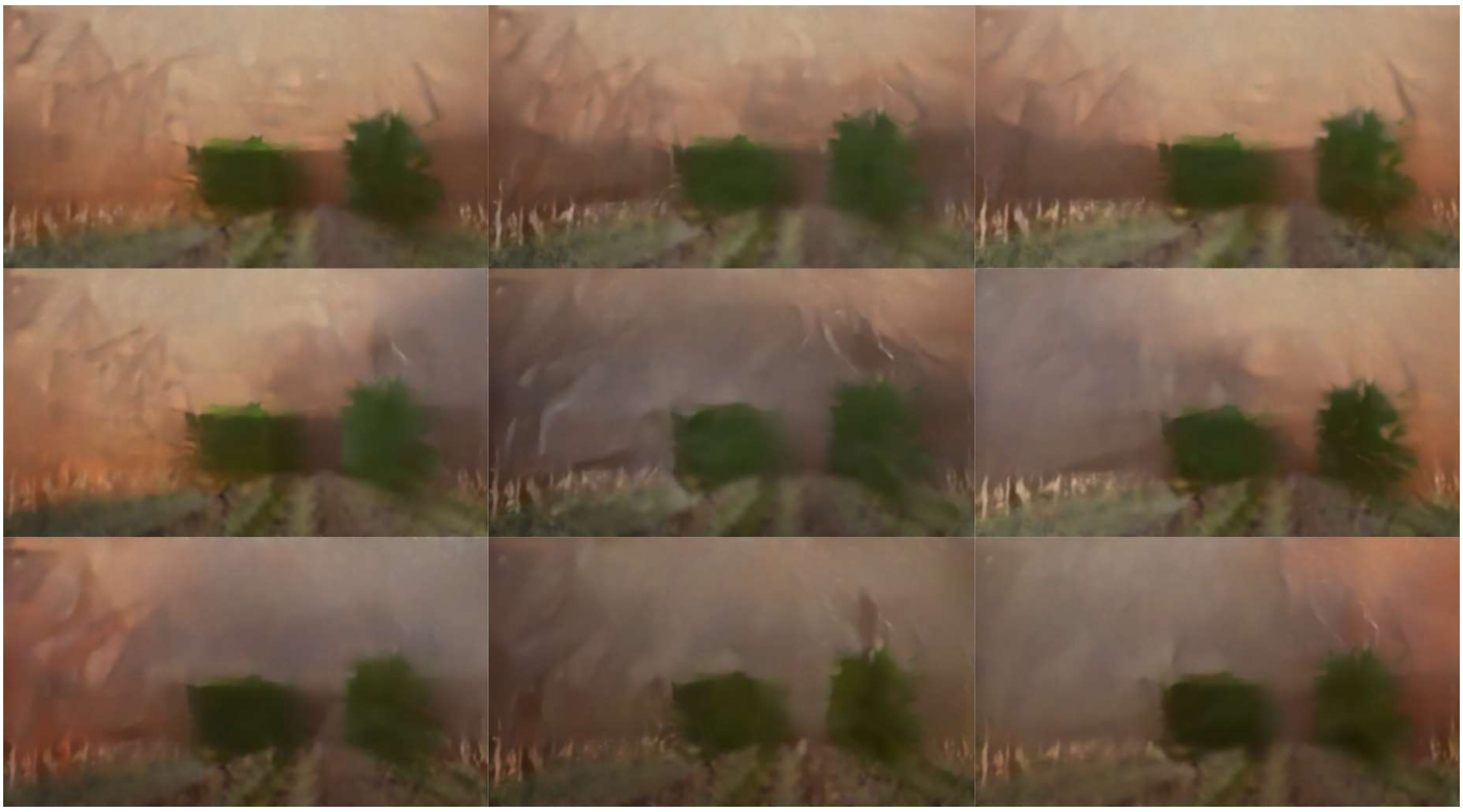
Expanded Greenhouse Design:

- Domed Greenhouses

Upon completing their permanent settlement, the crew will need to expand their greenhouse production in order to prepare for the arrival of a second crew in the coming years. A 15 square meter dome will prove the crew with amble room to begin to grow a wider variety of plants, diversifying their palette and enabling humans to become completely independent from prepackaged foods on another planet. Image 020 illustrates a perspective view inside one of these geodesic greenhouse domes on the martian surface. Upon completion, the crew will have automony in developing as many additional greenhouse domes that they deem necessary. This will be the final iteration of the ARES Mission cultivation process.



020



021

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Mars Greenhouse Research

Images:

- 001: NASA_Habitability Guidelines and Criteria_(p.82)_(Figure 4-7. Fifth and Ninety-Fifth Percentile Subjects Demonstrating Compression Standing)
- 002: RedMars_(p. 5)_(Table 2: Elemental Composition of Martian Soils)
- 003: Plant Physiology_(p.895)_(Figure 3.)
- 004: Plant Physiology_(p.897)_(Figure 5.)
- 005: Mars Rodwell Experiment Final Report_(p.40)_(Figure 6.1 Rodwell Prototype)
- 006: Bioscapes Collection (001)_Miller Logan
- 007: Bioscapes Collection (002)_Miller Logan
- 008: Bioscapes Collection (003)_Miller Logan
- 009: Bioscapes Collection (004)_Miller Logan
- 010: Rendered Bifurcation_Miller Logan
- 011: Greenhouse Plan_Miller Logan
- 012: Greenhouse Transverse Section_Miller Logan
- 013: Greenhouse Longitudional Section_Miller Logan
- 014: Greenhouse Interior Perspective (01)_Miller Logan
- 015: Greenhouse Interior Perspective (02)_Miller Logan
- 016: Greenhouse Exterior Perspective (Day)_Miller Logan
- 017: Greenhouse Exterior Perspective (Night)_Miller Logan
- 018: Greenhouse Packaging Diagram_Miller Logan
- 019: Greenhouse Packaging Matrix_Miller Logan
- 020: Greenhouse Dome Interior Perspective (01)_Miller Logan
- 021: Greenhouse Dome Matrix_Miller Logan

Sources:

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