Red Mars – Green Mars?
Mars Regolith as a Growing Medium

Embry-Riddle Aeronautical University
Daytona Beach, Florida

Advisor
Dr. Robert N. McGrath
Assistant Professor – Aviation Business Administration Department

Students

Rebecca Burgher
Tony DeTora
Holly Fisher
Michael Stein

1.0 Abstract

This project has been designed to determine if it is possible to grow plants that will provide a significant portion of the NASA-defined human nutritional requirements utilizing Martian regolith as the growing medium. Some alteration of the Martian regolith in addition to the introduction of a fertilizer is desirable in order to achieve this goal, but this alteration can be accomplished with little disruption to activities that are expected at a human-inhabited Mars base.

In 1987 Amos Banin "cautiously suggested that from the physical and chemical view points, the Martian soil may constitute an appropriate medium for plant growth." [1] With the Pathfinder science data confirming or supporting most of the necessary assumptions and estimates, it can now be suggested with much less caution that Martian soil is an appropriate medium. Despite this optimistic view, there will be no way to make this more than merely a suggestion until Martian regolith is either returned to earth or humans are finally brought to Mars.

2.0 NASA-defined Human Nutritional Requirements

Spaceflight introduces the human body to extremes not normally experienced in daily life. To supplement the body's natural protections for some of the negative effects that can occur, important nutrients must be included in an astronaut's diet.

To combat dehydration as well as reduce the risk of kidney stones, a recommended water intake of one milliliter per kcal of energy consumed. An average size astronaut of 70 kg requires about 3,000 kcal per day to remain at a constant weight and temperature. Because of the problem of calcium loss in weightlessness, fat should be a large component, (as high as 30 to 35 percent) of the astronaut's daily calorie intake. For the same reason, although a high protein diet would combat muscle loss, it would also impede calcium absorption, and therefore is recommended at 12 to 15 percent of the average diet, with further insight needed. [2]

A number of vitamins are also vital to an astronaut's health. Specifically, fat-soluble vitamins A, D, E, and K are necessary for both men and women. Water-soluble vitamins such as B_{12}, B_6, Thiamin, Riboflavin, Floate, Niacin, Biotin, and Pantothenic Acid are also important for human health. In addition to calcium, minerals such as phosphorous, magnesium, sodium, and potassium must be included in the diet of a long-term space traveler. Finally, trace elements such as iron, copper, manganese, fluoride, zinc, selenium, iodine, and chromium should be considered and included. [2]

After completing this study of essential nutrients, the following list of plants that could supply many of these necessary elements was developed. A mix of these 14 plants can provide nearly all of the required nutrients, with the lacking components being made up with vitamin/mineral supplements.

1. Wheat
2. Soybeans
3. Lettuce
4. Potato
5. Tomato
6. Spinach
7. Sweet Potato
8. Peanuts
9. Cow Peas
10. Dried Beans
11. Strawberry
12. Cabbage
13. Charod
14. Carrot

In addition to these 14 plants, a diet for a Mars base could be supplemented with celery, peppers, rice, snap beans, broccoli and various other plants to increase the variety of food consumed as well as maximizing nutrient inclusion without relying upon supplements. These inclusions will neither significantly effect the desired growing environment, nor increase the necessary growing area.

Vitamin and mineral supplements can be brought from earth to help provide the essentials to base inhabitants, and some foodstuffs could also be brought to further diversify the available foods.

3.0 Growth Requirements/ Preferences

All fourteen required varieties of plant identified have different temperature, light, soil type, moisture, and pH requirements for optimum growth. While potato and cabbage prefer a temperature range of 60°F – 70°F, and sweet potato prefers an even warmer 70°F – 80°F, wheat is optimized at a cooler temperature. Lettuce requires 1" of rain per week while wheat prefers fairly dry and soybeans prefer more moisture. Soybeans obtain their nitrogen from the air, not through the soil. Sweet potato prefers acidic soil while spinach doesn't grow well in acidic soil which may well prevent the use of Martian regolith for it's growth. Strawberry can grow in a variety of soil types while spinach prefers a sandy loam and carrot requires a deep, rich soil for optimization.

Optimum growth of all plants is not required, and some tradeoffs are required in order to develop a simple facility that can provide these needs. There will be several separate growing areas at differing levels of each of these requirements. Wheat will be grown by itself in a cool greenhouse with a constant day cycle to increase the yield. Other areas will have earth-normal day/night cycles and temperature range of either 60°F – 70°F or 70°F – 80°F.

Nutrients that are required for plant growth are broken down into macro-nutrients, those required on a large scale, and micro-nutrients, those that are required in much smaller scales. Macro-nutrients can not all be supplied by the Martian regolith, just as they can not be supplied by earth soil.

Table 1 – Macro-nutrient Levels in Terrestrial and Martian Soils [3]

Element	Terrestrial Soil (Avg wt %)	Mars Soil (Avg wt %)
N	0.14	Not determined
P	0.06	0.30
K	0.83	0.08
Ca	1.37	4.1
Mg	0.5	3.6
S	0.07	2.9

Micro-nutrients are also available in the Martian regolith. Fe is found in non-crystalline form, Zn, Cu and Mo are available at similar levels to that of earth soils.

4.0 Martian Regolith

The composition of Martian regolith appears to be uniform or nearly uniform throughout the planetary surface. This is most likely due to years, perhaps hundreds of millions of years, of storms carrying and intermixing the surface fines. [1] This theory is supported by the extreme similarities in the composition of the samples, as can be seen in Table 2, taken from each of the Viking sites as well as the Pathfinder soil data. The Viking sites are approximately 6500 km apart while the Pathfinder site is in a different hemisphere. [4]

The data provided from the regolith tested during the Pathfinder mission displayed slightly different qualities than the Viking tests as shown in Table 2, but Pathfinder was designed to provide a more detailed picture than the Viking missions. Both of these have differed to some degree from the SNC meteorites' composition, specifically in the increased presence of Si in the soil samples.

The oxides found during Mars Pathfinder mission using an Alpha Proton X-Ray Spectrometer agree with the inferred mineralogy from the Viking sites as can be seen in Table 3. The Viking landing craft were not equipped to directly measure the mineralogy of the soil, but the figures have been determined based upon the chemical composition and modeling.

The Martian regolith itself forms a loosely packed, porous medium in which plants will be able to grow and support the necessary root structures. Since the regolith contains a high proportion of smectite clays, the minerals stabilize the pH at the slightly acidic range (pH 5-6). These minerals also have a high exchange capacity, providing a large pool of exchangeable ions.

Table 2 – Elemental Composition of Martian Soils

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

Table 3 – Oxides in Martian Soils

Oxide	Pathfinder A-2, Soil [5]	Pathfinder A-4, Soil [5]	Pathfinder A-5, Soil [5]	Viking Chryse Planitia [7, 8]	Viking Utopia Planitia [7, 8]
	Weight %	Weight %	Weight %	Weight %	Weight %
Na_20	4.3	5.1	3.6	-	-
MgO	8.7	9.0	8.6	6	6
Al_2O_3	8.0	10.4	10.1	7.3	7*
SiO_2	46.1	43.3	43.8	44	43
SO_3	4.3	6.2	5.4	6.7	7.9
K_2O	0.6	0.7	0.7	<0.5	<0.5
CaO	6.3	4.8	5.3	5.7	5.7
TiO_2	1.1	1.1	0.7	0.62	0.54
MnO	0.5	0.5	0.6	-	-
Fe_2O_3	19.5	14.5	17.5	17.5	17.3
Cl	-	-	-	0.8	0.4
Other	-	-	-	2	2
Totals (approx)	99	96	96	91	90

* Inferred from available data

5.0 Comparison of Regolith to Requirements

Plants require N, P, K, Ca, Mg and S in considerable quantities and Fe, Mn, Zn, Cu, B and Mo in trace quantities. The Martian regolith contains P, Ca, Mg, S, Fe, Zn, Cu and Mo in sufficient quantities. N is available in the atmosphere, but it is not expected to provide the full needs of plant growth. K is available in small amounts in the regolith – this will also need to be supplemented. There is no evidence of B on the planet Mars. Mn is present in the Shergotty meteorite in amounts of less than 0.5% by weight. [3]

Most of the elements that are required are available, but the specific detailed mineralogy and the ease with which the plants could use them in their present form is unknown. Fertilization will be needed to provide some essential elements.

Other elements provide special concern due to the specific nature of the Martian regolith. Aluminum is present in a smaller concentration than is common in earth soils, but due to the acidic conditions on Mars, it may be a toxic level for plants. Chloride is found in amounts that may prevent plant life from taking in water, which would have an immediately detrimental effect upon the plants in question. [3]

6.0 Genetic Alteration of Plants

Some of the plants might be altered through the use of genetic engineering to more suitably inhabit the Martian landscape, or a controlled environment utilizing Martian regolith. Most genetic alteration of plants involves splicing genes specifically to confer resistance to some form of virus or insect. There have been advances, however, in providing plants with drought resistance, increased iron content and tolerance to normally toxic levels of aluminum. [9] These alterations are truly beyond the scope of this paper, the students involved and most of the individuals worldwide working on genetic engineering of plants.

7.0 Alteration of Regolith to Meet Growth Requirements

Clearly, the addition of a fertilizer will be required to produce the desired plants on Mars in a healthy environment. This fertilizer will need to provide significant nitrogen and potassium levels plus small amounts of manganese and boron. In the extremely unlikely situation that one of the elements contained in the Martian regolith is in a form that can not be easily utilized by the plants, there will need to be additional steps taken to ensure acceptable nutrient solubility and usability.

The aluminum and chloride presence in the regolith will need to be counteracted or the elements will need to be removed from the soil. Silicon has been shown to prevent toxicity of metals, but it is unclear how well this will work in the Martian environment. [10] This problem may be overcome by leaching the excess soluble salts from the regolith.

8.0 Preliminary Greenhouse Configuration

The greenhouse configuration can be seen in Figure 1 and is designed to separate the plant growth into six different areas. Each of these greenhouses is identical, provides a "shirtsleeve" environment, and will provide the desired temperature, humidity and pressure. The airlocks attach each greenhouse to a tunnel system as shown in Figure 2. This tunnel system provides for easy movement between the different greenhouse areas and allows for future expansion.

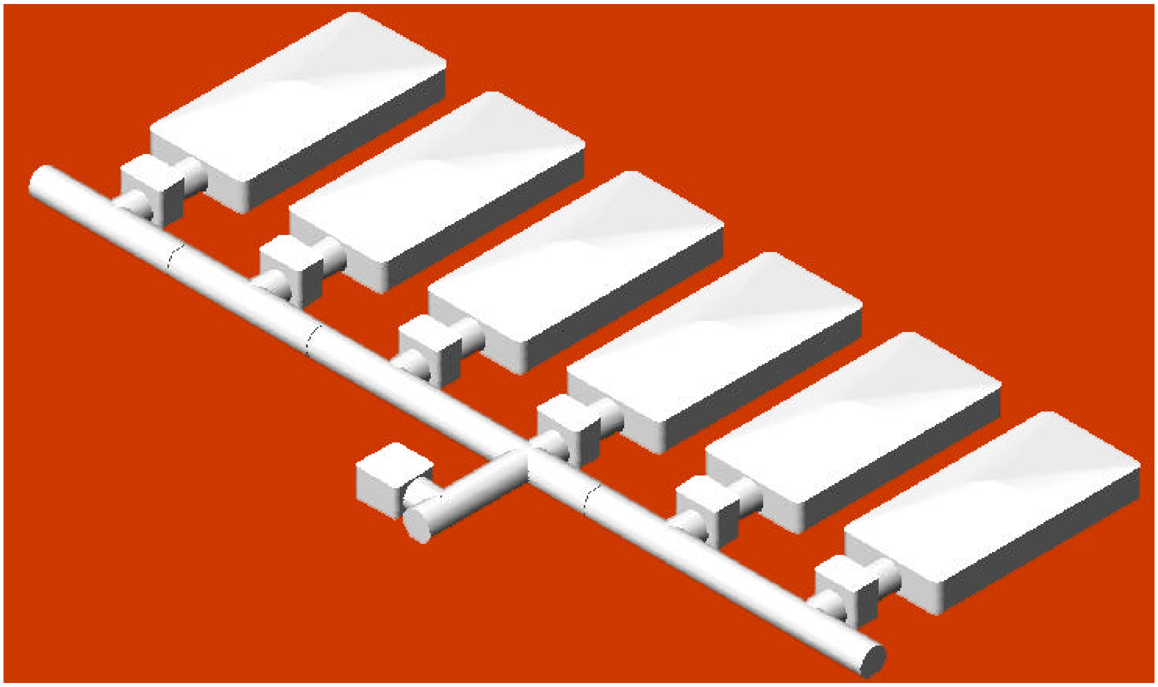

Figure 1 – Greenhouse Array

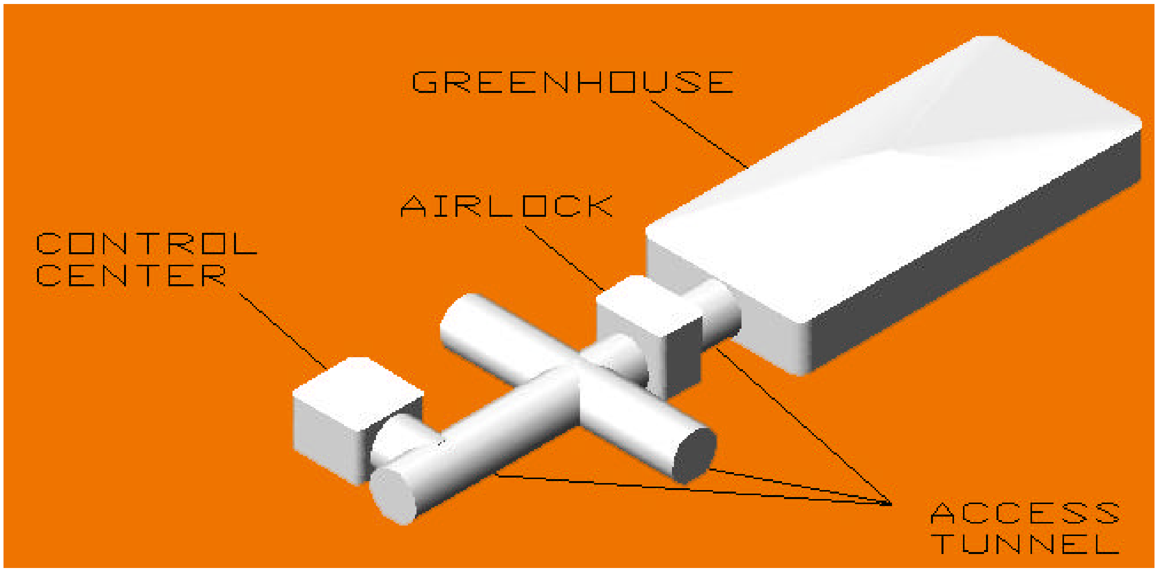

Figure 2 – Single Greenhouse

Each greenhouse has the same layout, enabling each to be used for any of the growing environments. This layout configuration can be viewed in Figure 3. Figure 4 provides a top view of a single greenhouse while Figure 5 provides a side view of the configuration.

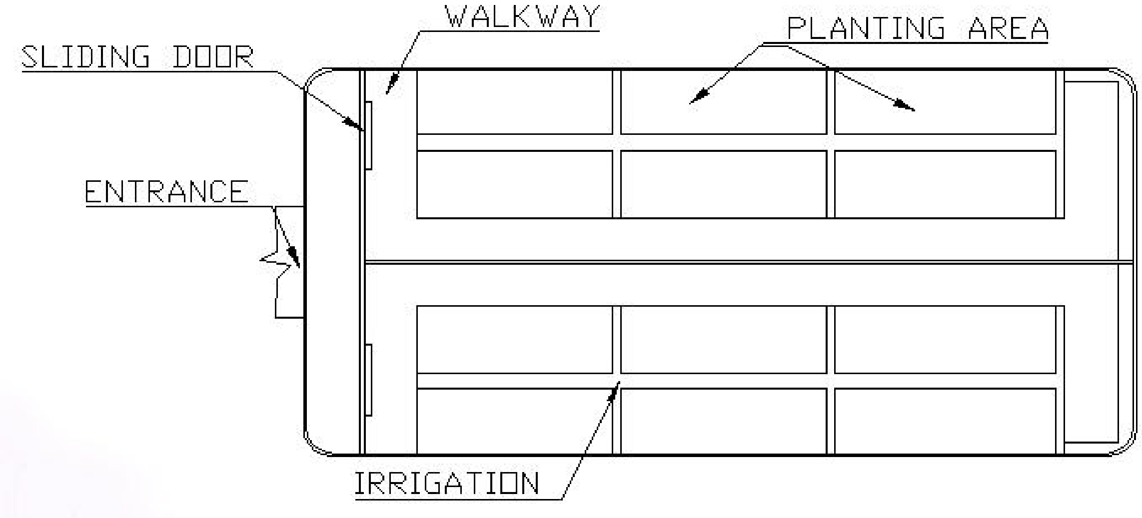

Figure 3 – Layout: Single Greenhouse

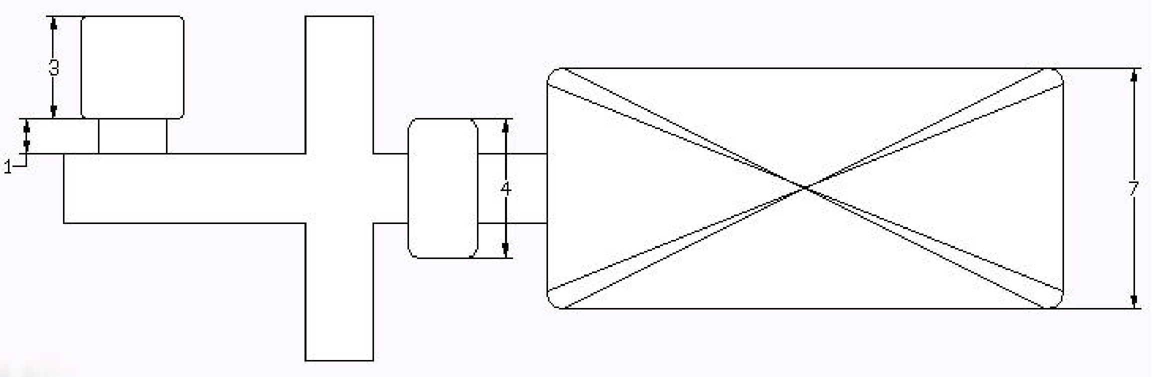

Figure 4 – Top View: Single Greenhouse [All Dimensions in meters]

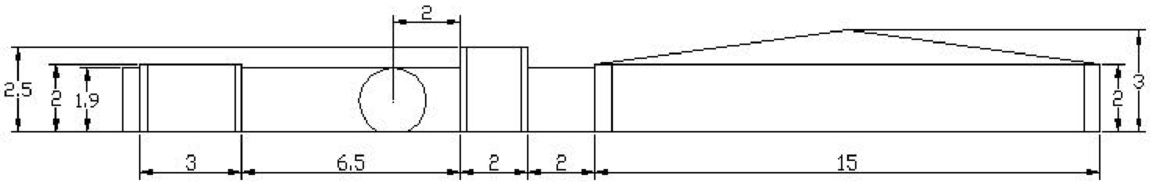

Figure 5 – Side View: Single Greenhouse [All Dimensions in meters]

9.0 Conclusion

Although certain assumptions can be made at this time based upon the information that is currently available, no real answers to the main question can be resolved without increased knowledge about the Martian regolith. There appear to be no major obstacles to the utilization of regolith as a growing medium, but the unknowns continue to be considerable.

The data received from the Pathfinder mission were astounding in their variety, complexity and relative consistency with the Viking data from 20 years earlier. This variety, complexity and relative consistency has not led to any major new insights on this specific topic. No new evidence was uncovered to bolster or refute a claim of regolith as a growing medium.

Ideas regarding the use of Martian regolith as a growing medium have been published as early as 1987 [1] when much less was specifically known about the composition of the Martian regolith. With the Pathfinder science data confirming most of the existing estimates and assumptions, the work that Banin, Stoker, Ming and others have done are now more confidently the proper path to follow. The path, however, is blocked by a lack of knowledge.

What is truly needed to glean greater insight into the issue is Martian regolith. This can be achieved by bringing regolith back to humans to test it or by bringing humans to Mars.

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