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Project HOME Hydroponic Operations for Mars Exploration

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Abstract

This report considers the challenges NASA, SpaceX, and other private companies will face in the approaching two decades when sending astronauts on missions to Mars. The longest exploration is planned to take place in the 2030's, sending a crew of, at minimum, four astronauts to Mars for a year of research. The research conducted is assisting space exploration companies' with ways to grow a complete diet on a planet that does not receive enough sunlight. Agriculture in enclosed and buried structures on Mars will enable astronauts to conduct extended surface exploration missions. We evaluated a deep-water culture indoor hydroponics system to grow Moringa oleifera (M. Oleifera), a nutrient- and antioxidant-rich plant with leaves containing all nine essential amino acids. After initial aquaponics growth and 3 prior harvests, the lighting intensity was set to 590 W/m^2 in a twelve hour on/off cycle, in normal indoor atmosphere. This simulates an ambient light collection and reflection system on Mars illuminating an insulated, pressurized underground chamber for agriculture. All plants (N = 32) were harvested 17 times over a 9 month period at regular intervals, when plant heights reached an average of 0.9 m. Consumable leaf yield averaged 0.18 dry g per plant per day. Data suggests that M. Oleifera as a perennial hydroponic crop is possible under reduced illumination, and is a candidate food source for Mars explorers. Preliminary research has expanded to utilizing natural light, five additional plants, three more hydroponic systems, and greenhouse ran entirely by solar power. Currently a solar powered eight by twelve foot greenhouse is being used to hydroponically grow goji berries, M. Oleifera, bamboo, kale, chia, and sweet potatoes. When these foods are combined with each other they contain a complete necessary set of amino acids, vitamins, minerals, fiber, carbohydrates, and nutrients for a balanced human diet. The plants receive 590 W/m^2 by utilizing a shade cloth over the entire greenhouse and the solar panels. In conclusion, the report states that NASA, and alike companies, will obtain valuable stepping stones in future missions to Mars by maximizing the growth of superfoods with utilization of natural light, and a focus on a hydroponics system as the farming method for space.

Introduction

NASA is developing the capability to have manned missions to Mars as soon as 2030 – goals outlined in the bipartisan NASA Authorization Act of 2010 and in the 2010 U.S. National Space Policy (MEPAG, 2010). Furthered space travel has been a dream for many decades and is becoming a forerunner in today's research due to the longevity of the human race on Earth being highly questioned. It is evident that a need for relocation in the near future will be necessary due to Earth's atmosphere becoming obsolete and humans hastily reducing resources faster than they can be replenished. Geologically, Mars is comparable to Antarctica, proving it fit for Martian colonist to live on the surface and not in tunnels. Additionally, Mars has the predicted environment suitable for the harvesting of wind power aside from purely solar power, allowing for energy to power basic life needs. The prior facts allow for the chances of habitability of Mars to be favorable, while creating a rush on research to make colonization a reality.

The extended distance to Mars makes for an approximate seven-month trip from Earth. It is estimated to take a year to get an accurate amount of data to further determine survivability on Mars, and in total it will take two and a half to three years (Petranek, 2015). Currently it costs $10,000 to put a pound of payload into Earth's orbit (Boen, 2008). Sending adequate amounts of food to last three years at a farther distance is financially impossible, further confirming the need to garden on Mars. Also, when in transport, food loses a significant number of key vitamins and nutrients, such as Vitamin A, Vitamin C, and thia-4 chemicals, making them less beneficial to a balanced diet. The issue with growing directly on Mars is the toxic number of perchlorates found in Mars' regolith, or dusty soil.

In 2015 evidence proving the existence of water on Mars' surface was released, published in Nature Geoscience it was announced that the Mars Reconnaissance Orbiter found hydrated perchlorate, i.e. salty water. The discovery showed a sludgy mess of water only appearing in the warmer seasons on Mars, unlike a normal stream or river found on Earth. It was discovered through the analysis of dark streaks on the surface called recurring slope lineage (RSL). Readings showed an approximate water content of 3%, which is comparable to the driest deserts on Earth (Brown, 2016). These levels of water would be too toxic for human consumption but will support bacteria and other microbes living in it. Despite being a large stepping stone for researches, the issue remains in the amount of water on Mars. Being extremely limited and difficult to purify for human consumption, a hydroponics system that saves 80% of the water stands as the most qualified to meet NASA's growing efforts (Martinez, 1970).

The goal of the research is to determine if the use of a hydroponics systems growing goji berries, M. Oleifera, bamboo, kale, chia, and sweet potatoes will benefit these space exploration companies' search to find a practical way to provide astronauts nutrient packed food. Within the past five years researchers have attempted to grow plants in regolith, despite knowing the detrimental effects the toxins in the soil have to humans. In addition, information has been released supporting the presumption the amount of water is insufficient to water crops. A hydroponics system like the one in the research will take away the problems with growing in regolith, and according to Martinez (1970), will save 80% of the water used. Wieger Wamelink, a senior ecologist at Wageningen University & Research worked in collaboration with Mars One on an experiment attempting to grow plants such as cress, sting nettle, and field mustard in regolith (2016). The plants that were researched do not contain enough nutrients to be useful and are challenging to incorporate into a menu. It is imperative to focus on growing plants such as M. Oleifera, or the "The Tree of Life", that contain the vitamins, antioxidants, and amino acids essential to a complete diet. Researching the most health beneficial plants will aid in efforts of providing the astronauts with a balanced diet.

Lastly, prior research efforts to grow plants on Mars failed to account for the light intensity and spectrum received on Mars. With half the amount of light received on Earth at solar noon it is a major challenge to have plants successfully grow without supplemental lights (Brown, 2016). The proposed research has the plants receiving 590W/m^2 to replicate the light intensity on Mars, and to determine if they can not only sustain life with significantly reduced light, but still provide sufficient yield. The greenhouse and solar panels are currently shaded to replicate the same lighting conditions as Mars. The goal is to sustain an off-the grid greenhouse able to successfully function for an entire year using Mars lighting conditions.

Literature Review

Transportation

It is predicted that shipping food from Earth to Mars will cost $1 billion per person per year. Aldrin states in an interview with Florida Technical Institute that, "You can't sustain civilization if you have to ship everything," (Researchers, 2016). The trip is estimated to take two and a half years roughly from the seven month trip to and from and a year of research on the planet (Petranek, 2015). When astronauts travel into space, NASA scientists determine how much food will be needed for each mission. For example, an astronaut on the ISS uses about 1.83 pounds (0.83 kilograms) of food per meal each day. About 0.27 pounds (0.12 kilograms) of this weight is packaging material (Dunbar, 2007). Longer missions require much more food for example a four-man mission for three years to Mars is predicted to use an 24,000 pounds (10,886 kilograms) of food says Bob Allen editor of NASA Fact Sheet in 2007 (Dunbar, 2007) . Michele

Perchonok, Ph.D., manages NASA's shuttle food system and works on the Advanced Food Technology project, which she spoke about in a presentation at the fifth annual Food Technology Innovation & Safety Forum in May. When considering food for space travel she states, "We have these four requirements: nutritious, safe, acceptable and minimizing resources, and 'acceptable' includes variety" (Andrews, 2011). Besides the cost of sending all the food to Mars the other issue is the amount of nutrient degradation that happens to the food over time. Nutrients like Vitamin A, Vitamin C, and thiamine all drop in concentration dramatically over time, even after just a year in the pouch. Grace Douglas, a food technology scientist at NASA's Johnson Space Center, notes that, "Keeping the vitamin levels in food high is another big concern. Even in frozen food, vitamins slowly degrade as they react with oxygen, and in the depths of space, without a varied diet it would be easy for astronauts to miss out key vitamins. Tablets aren't much of a solution, as they can degrade too and astronauts are more likely to forget to take a tablet than skip a meal altogether" (Reynolds, 2019). Therefore, not only will growing plants on Mars be beneficial to the mission, but growing plants like M. Oleifera which contain the complete set of amino acids and nutrients for a daily diet would be most valuable.

Regolith

One of the biggest questions facing NASA is whether to pack all of the food required for the two-and-a-half-year trip from Earth to Mars and back or to figure out a way to grow food on Mars. "Soil, by definition, contains organics; it has held plant life, insects, and worms. Mars doesn't really have soil," said Ralph Fritsche, the senior project manager for food production at Kennedy Space Center (Heiney, 2016). Mars is instead covered with volcanic rock called regolith which contains many toxic chemicals creating a more complex problem. Florida Tech Buzz Aldrin Space Institute in Melbourne, Florida is collaborating with NASA to grow plants on a simulated Martian garden. The 100 pounds of Martian soil simulant being used at Florida Tech comes from Hawaii and was chosen based on spectral data from Mars orbiters (Heiney, 2016). The study began with 30 seeds planted in the simulant-only tubes and ended with only half as many; although they tasted the same as the others, their roots were not as strong as the potting soil plants. This preliminary research showed the importance on understanding how timelines differ between farming on Mars compared to Earth, as it found that germination rates were two to three days slower than in control groups. The regolith on Mars also found Perchlorates which are reactive chemicals first detected in arctic Martian soil by NASA's Phoenix lander that plopped down on Mars over five years ago in May 2008 (MEPAG). Perchlorates are actually a very important component of soil. However, the high amount on Mars is toxic to humans. Aside from the regolith containing toxic amounts of perchlorates, Simon Gilroy, a botanist at the University of Wisconsin-Madison who researches the effects of gravity on plant growth, states that, "Watering plants in space is really hard because water moves differently because there's no gravity. If you get the water onto soil particles, it'll just creep over the surface." Thus, showing even greater benefits of farming in a hydroponics system (Plackett, 2019).

The Gap in the Research

The purpose of this study is to determine if the use of a hydroponics systems growing M. Oleifera will benefit NASA's search to find a practical way to provide astronauts with an easy and productive way to grow nutrient packed food. Within the past five years researchers have been trying to grow plants in regolith even though science knows the detrimental effects that the toxins in the soil have to humans. In addition to this information scientist understand the lack of water that is available to water crops. Researchers are trying to terraform Mars into an Earth where we have always grown food in the soil. If we were to try a hydroponics system like the one in the research which would take away the regolith and according to Martinez (1970) save 80% of the water used we would be saving a lot of time and energy into unneeded research while finding a practical way to grow food (1970). Not to mention by growing crops on Mars, we will also be addressing the lack of oxygen issue. Dr. John Millis (2018), who holds a Ph.D. in Physics and Astronomy and is a former writer for ThoughtCo, states that, "The problems of food and air will have to be solved through creative means. Growing plants that produce both food and oxygen is a good start." Missions to places with less gravity, where exercise is challenging and limited, have shown extreme reduction in our muscles and bones from recent astronauts. Researching the most health beneficial plants would help NASA's efforts into providing the astronauts with a nutritious diet plan. The other item left to question is sunlight. As mentioned previously, Mars only receives half of the light Earth receives at solar noon. This is why in this research project the plants are only receiving 590W/m2 to replicate the light intensity on Mars and determine if they could sustain life there with 60% less light.

Data

Prelimiary Research

Preliminary research for this project was done from January 2017 - January 2018, determining how well M. Oleifera would grow if it was only exposed to Mars sunlight in a controlled hydroponics system. Thirty-two (32) M. Oleifera trees were harvested over a 9 month period at regular intervals when plant heights reached an average of 0.9 m. Table 1 shows the harvest dates, the total amount of leaves, in grams, harvested from the 32 trees shown in Figure 1, the amount of time in between harvests, and the normalized dry weight per day. The weight of the harvested leaves was obtained by trimming all of the trees down to the same height, removing the leaves from the cut stems, and drying them in a food grade dehydrator before being placed on a scale to determine the total amount of dry leaves harvested from all 32 plants. The normalized dry weight per day was calculated by taking the total weight of the harvested dry leaves, and dividing them by the number of days in between harvests. These normalized values were then averaged together to obtain an overall average value of 7.17 grams from the results collected over the 20 harvests. This can be broken down even further by dividing that average number by the total number of trees to obtain the normalized dry leaves weight produced by each tree to be 0.224 grams/tree.

Figure 1: The Moringa Oleifera trees growing under reduced artificial

After talking to a nutritionist (who wished to be kept anonymous) at Embry-Riddle Aeronautical University's Daytona Beach campus we were able to create a list of important nutrients and the average amounts of each nutrient humans require to take in daily, to assess the feasibility of using M. Oleifera as a source of food for astronauts on Mars. Table 2 shows a list of these nutrients, the average daily amount required by humans, the value of said nutrient that 1g of dry M. Oleifera leaves provides, the amount of dry leaves needed to meet the average human needs, and how many M. Oleifera trees would be required to produce this amount of leaves. The nutrients we decided to assess during this stage of research were protein, energy, potassium, calcium, vitamin A, and vitamin C. The average daily amount humans required were initially obtained from the school nutritionist, and then confirmed through internet research. The value per 1g of dry M. Oleifera leaves was obtained from the USDA plant database. By taking the amount humans require and dividing it by the amount 1g of dry leaves provides, we were able to calculate the amount of dry leaves we would need to obtain these values. This value was then multiplied by the average number of dry leaves produced by one (1) M. Oleifera tree, or 0.224 grams/tree, calculated above from Table 1.

Looking at the above results it's clear to see that while M. Oleifera is certainly better for some of the nutrients, such as energy and vitamin A, even in its worst category, potassium, it's still not unreasonable to have a greenhouse large enough to grow 200+ plants. However, with this research project focusing on superfoods, and not just M. Oleifera, table 2 does a great job of demonstrating how growing different types of plants would prove beneficial. Future research will focus on other plants, such goji berries, kale, sweet potatoes, chia seeds, spirulina, and hemp seeds to help meet these needs without having to only grow, and eat, M. Oleifera. Each plant strives in a certain nutrient class, for example M. Oleifera is great for energy and Vitamin A, but spirulina is better for potassium and kale is better for vitamin C, and in future research we hope to determine how many of each type of plant will need to be grown to fulfill a full diet, while utilizing a variety of foods, and requiring a minimum amount of space.

Methodology

Funding for System

Looking at the above results it's clear to see that while M. Oleifera is certainly better for some of the nutrients, such as energy and vitamin A, even in its worst category, potassium, it's still not unreasonable to have a greenhouse large enough to grow 200+ plants. However, with this research project focusing on superfoods, and not just M. Oleifera, table 2 does a great job of demonstrating how growing different types of plants would prove beneficial. Future research will focus on other plants, such goji berries, kale, sweet potatoes, chia seeds, spirulina, and hemp seeds to help meet these needs without having to only grow, and eat, M. Oleifera. Each plant strives in a certain nutrient class, for example M. Oleifera is great for energy and Vitamin A, but spirulina is better for potassium and kale is better for vitamin C, and in future research we hope to determine how many of each type of plant will need to be grown to fulfill a full diet, while utilizing a variety of foods, and requiring a minimum amount of space.

Mars-Sun-Earth Relationship

Figure 2 below shows the Mars-Sun-Earth relationship in regards to distance and amount of light received from the Sun. Mars only receives 590W/m^2 of solar irradiance (sunlight) while Earth receives 1050W/m^2 of solar irradiance due to the greater distance between Mars and the sun. The greenhouse is covered with a shade cloth that reflects 40% of the sunlight directed at it so it can resemble that same solar irradiance that would be taking place if it were on Mars. The solar panels are also covered with that shade cloth so the power they receive is reduced 60%. The light is measured daily using a Par Meter, which is a quantum sensor that measures the PAR waveband (400-700 nm). The plants in the greenhouse receive reduced sunlight to portray the Mars environment. While Earth has about 12 hours of sunlight and 12 hours of darkness, a Mars' day is very close to Earth's day. A day, or sol, on Mars last 24 hours, 39 minutes, and 35 seconds (Heiney, 2016).

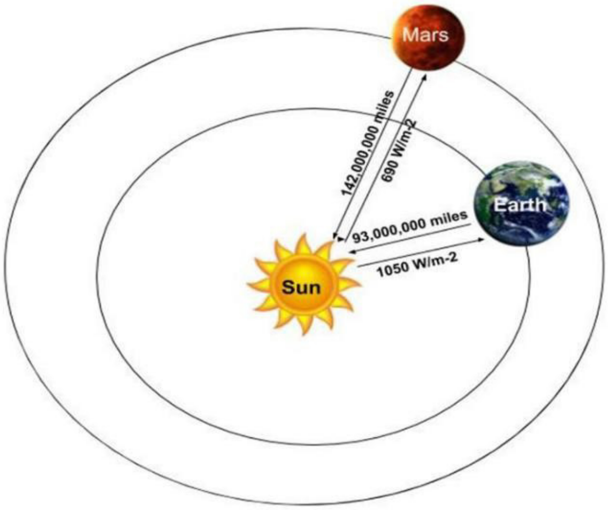

Figure 2: Mars-Sun-Earth Diagram

Data Collection

Data collection will vary based off each plant. Essentially, once the plants reach harvestable growth they will be trimmed to the seedling height and the plant part that is harvested will be dehydrated using a dehydrator. Dehydrating the plants takes out the water in the plants which is an inconsistent amount and would affect the weight measured. These weights will be compared to what the USDA reports that each plant should be producing in traditional agriculture. This information will show if the plants grew efficiently in the experiment. The goal is to create a very basic greenhouse which, with little expertise, anyone could use and be successful with.

Discussion

The preliminary research done in this project showed that a superfood can grow under the reduced sunlight that is received on Mars. This initial experiment needs to be replicated for accuracy and in order to guarantee that the plants grew at the rate that was observed with the same conditions. From what was experimented it does show that M. Oleifera will grow on Mars if the same lighting conditions are replicated and there is no supplemented sunlight. As Table 2 shows, it is reasonable to plant M. Oleifera on Mars with the amount of plants required in order to supplement the amount of nutrients needed in a diet. This initial experiment has set the building blocks for our current experiment. The research has expanded so that five plants are growing under simulated Mars sunlight in a solar powered greenhouse. The only factor being tested is how well the plants grow under Mars sunlight and if they will provide us with enough food to survive off of on Mars. The atmosphere is set to standard Earth atmosphere, so the Mars atmosphere is not accounted for. That will definitely change the way the plants grow because Mars is 96% carbon dioxide. Carbon dioxide is actually supplemented into growing chambers to make plants grow, but at the abundance there is on Mars, there is no telling if that will positively or negatively impact the growth of the plants. Temperature is also not accounted for. The temperature varies based on what the outdoors temperature is in Daytona Beach, Florida, and is measured daily. The temperature on Mars varies from 20 C to 200 C. These plants will not grow in freezing conditions so the greenhouse on Mars will have to be heated in order to get the same performance that this experiment is receiving. Solar radiation is not considered either. Mars' atmosphere is thinner than Earth's, and solar radiation can be toxic to plants if it is received in abundance. Further research would determine how much radiation the plants can be exposed to before becoming toxic to humans. Overall, it is believed that the plants would have to be underground or in an enclosed structure to eliminate radiation from touching the plants. Dust storms are also not taken into account, which may affect the solar panels providing power to the greenhouse. As seen from other solar powered rovers on the planet doing research, dust storms can pour sand over the solar panels of the rovers and stop them from working. This could easily happen to the solar panels of the greenhouse and a mechanism for removing the dust immediately would have to be solved in order to prevent such error. Seasons are not taken into account either. While Mars has similar seasons, they are double the time that Earths are. A six-month summer might be good for plant yield, but a six month winter might be detrimental. More study on the seasons of Mars will have to be done before we can simulate the seasons in an experiment. The goal is to have these five plants produce enough food that an astronaut could survive off of when grown with a reduced amount of sunlight. Once this is guaranteed then future research can be conducted to test out other factors that will affect the plants and the greenhouse.

Conclusion

The basis of the research is to discover the feasibility of growing and harvesting superfoods in Mars sunlight, while optimizing the growth of such foods to obtain optimal output year-round. Due to the current direction space travel is heading, it is imperative to establish successful means of food production to secure survivability on Mars with the guarantee of a sustainable diet. The research will be most useful for members of companies such as NASA and SpaceX, specifically the horticulturist departments. With dehydrated food being the primary source of nutrition for astronauts, continuing to send such food to space will prove to be economically inefficient due to the increased distance of travel, decreased nutritional degradation factors, and necessity for recurring missions. The introduction of nutritionally dense superfoods that can be grown in abnormal environments will aid in the success of missions and significantly lower costs. Furthermore, the inclusion of solar panels into the research project allows for the greenhouse to run self-sufficiently and be adaptable to un-civilized conditions. With proper maintenance the plants will display positive growth levels with lower levels of solar intensity than provided on Earth to simulate Mars' lighting conditions.

Recommendations

With the current research project underway we expect to have results showing that the plants being grown can grow in a hydroponics system and will grow efficiently so that they will be considered worthy to grow on Mars. While there is plenty of research being done to see how well plants grow in the regolith on Mars and under Mars atmospheric condition it is most important to understand how well they will grow with the reduced amount of sunlight because that is one of the most crucial parts of the success of a plant to grow. Knowing that a complete diet can be grown in a hydroponic system with reduced sunlight will further a lot of research that is being conducted around the world. Having plants adapt to those conditions shows the hardiness of them and allows for researchers to test other conditions to see the success rate. After this is guaranteed then researchers can start to look at temperature, humidity, radiation, and other factors that will matter now we know the plants can grow. In conclusion, seeing how well superfoods grow under Mars sunlight is the starting point to growing food for astronauts.

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Appendix 1

Harvest #	Harvest Date (mm/dd/yyy)	Weight of Dry Leaves Harvested, W [g]	# of Days Between Harvests, n [days]	Normalized Dry Weight Per Day [g] (harvest weight / no. days)
1	10/30/2016	49.4	-	-
2	11/14/2016	90.5	14	6.46
3	11/30/2016	81.3	16	5.08
4	1/14/2017	167.9	45	3.73
5	2/16/2017	37.5	33	1.14
6	3/9/2017	162.4	21	7.73
7	4/4/2017	140.8	26	5.42
8	4/17/2017	190	13	14.62
9	5/19/2017	196.3	32	6.13
10	6/6/2017	117.1	18	6.51
11	6/20/2017	169.6	14	12.11
12	7/6/2017	108.4	16	6.78
13	7/24/2017	142.2	18	7.90
14	8/7/2017	136.7	14	9.76
15	8/28/2017	139.4	21	6.64
16	9/25/2017	155.5	26	5.98
17	10/12/2017	133.8	17	7.87
18	10/26/2017	156	14	11.14
19	11/19/2017	149	23	6.48
20	1/13/2018	258.5	55	4.70
Average Normalized Dry Weight Per Day Obtained from 32 M. Oleifera Trees:				7.17

Table 1: Results obtained from harvesting 32 Moringa Oleifera trees 20 times between October 30, 2016 and January 13, 2018. The data suggests that the average normalized dry weight per day of 32 trees was 7.17 grams

Appendix 2

Nutrient	Amount Humans Require Per Day	Value Per 1g of Dry M. Oleifera Leaves	Amount of Dry Leaves Needed to Meet Human Needs [g]	Amount of M. Oleifera plants to produce required amount of dry leaves
Protein [g]	51	0.094	542.55	121.74
Energy [calories]	2000	64	31.25	7.01
Potassium, K [mg]	3500	3.37	1038.58	233.03
Calcium, Ca [mg]	1000	1.85	540.54	121.28
Vitamin A [μg]	900	3.78	238.10	53.42
Vitamin C [mg]	400	0.517	773.69	173.60

Table 2: A list of nutrients which shows how much of each nutrient is required for daily human consumption, the amount of each nutrient 1g of dry M. Oleifera leaves provides, the total amount of leaves required to meet the values required by humans, and the total number of trees that would need to be harvested to fulfill these needs.