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Planting and Germination of Sweet Potato, Yam and Radish Plants in the Mars Desert Research Station

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Abstract:

As part of the future exploration of the universe, manned missions to other planets or satellites near Earth will be needed. One of the main objectives of these missions will be to reach Mars because it is at a relatively close distance to our planet and because both planets have some common characteristics. Since the economic investment of these explorations is quite high, the duration of them must be significant; that's why the missions should aim to be self-sufficient. The search for food sources for crew members is a key factor to be investigated and even more attention should be on food whose production is possible and sustainable in the environment where the mission arises. This work was involved with the planting and germination of radish, yam and sweet potato plants in the greenhouse of the Mars Desert Research Station (MDRS) and the main objective was to investigate the characteristics of growth and development of these plants in Martian conditions to find out whether its production is possible or not. Orange skin and white skin: two types of sweet potatoes were planted. During rotation, it was discovered that yam grew faster under these conditions than the rest of the tubers, although its development was slower as compared to terrestrial conditions. Radish plants in Mars regolith grew in a similar speed than in the fertile Earth soil, and even faster than in drier soil taken from the desert. According to the results, the water and sunlight may have a significant contribution to the growth of plants, therefore it must be ensured that these two resources are held in the required amounts.

Introduction

Humans have always been curious about the outer space. From the ancient cultures that were able to precisely predict eclipses to the astronauts who walked on the Moon, the observation of the night sky and the intention to explore the universe has led us to important achievements that provide valuable information to make possible and successful future human missions to the Moon or other planets. Considering the Moon as the first place we might aim to go due to its relative closeness to the Earth, Mars is definitely the second target of a manned expedition. Mars has many physical properties that are similar to those of our planet. The most remarkable similitude is the day/night cycle (24 hours on Earth and 24 hours 37 minutes on Mars). This similarity is important as plants have adapted to photosynthesize when the sun shines (McKay,

1999). Several scientists have concluded that we will adapt the life conditions on Mars, making it suitable for human life. All the technology needed to make possible the expedition to Mars is expensive, so the economic investment will be high. The duration of the expedition must be considerable to compensate for the money invested and a longer stay may lead to more benefits. Even though it may seem obvious, it is important to mention that those humans who will settle on Mars will have to eat there. As eating is vital for human survival, this aspect is a key factor that should be given special attention. The missions should aim to be self-sufficient, basically in terms of food for the members of the crew. People's health and performance depend on the food they eat. Crew members may experience food boredom after 3 months (Hunter, 2012); that's why they should have a variety of options. They must have at their disposal food combinations that contribute to a balanced diet according to their requirements, and fresh food must be part of that diet. Fresh food is free of harsh chemicals and additives, so it is healthier. Crew members would also enjoy food whose taste is better than the taste of dry food. Another advantage of fresh food is that it reduces packaging waste (Hunter, 2012). If crew members pretend to have fresh food, they will definitely have to learn how to grow plants in an inhospitable and unfavorable environment with no liquid water or oxygen, and with only a 43% of the sunlight our planet receives (Moskowitz, 2013). It is impossible to carry fresh food from Earth to feed every member of the crew during the whole mission, so Mars agriculture will be the solution. "An alternative could be to cultivate plants at the site itself, preferably in native soils" (Wamelink et al., 2014). Having a space designed only for food growth would also contribute to have a place in which crew members would be able to observe a natural environment, different from all the machines they will be used to live with. It may contribute to psychological comforts of crews and to have cleaner air.

Conditions of growth systems

Some experts claim that the first humans to live in Mars might be more identified as farmers than as astronauts (Moskowitz, 2013), so learning how to grow food in this planet will be a vital and challenging activity to ensure their survival. Food production will be mainly done in the greenhouse modules and, fortunately, Mars does have some amenities for agricultural purposes (Miller, 1999). We have information provided by Mars explorations about the composition of the Martian regolith. It contains essential minerals for the growth of plants in sufficient quantities, except from nitrogen (Wamelink et al., 2014). Plants must be able to grow in limited conditions in Mars regolith, whose bioavailability is low if we compare it with fertile Earth soil. However, researchers have discovered that some plants grow better in simulated Mars soil than in nutrient-poor Earth soils. The same thing happens if Mars soil and lunar soil are compared: results are more favorable using Mars regolith (Stromberg, 2014). Unfortunately, it's still unknown if the low availability of nitrogen in the Mars regolith may lead to early crops death. In case that the amount of food produced is not meaningful, nitrogen-fixers could be used in addition with the Mars regolith to create a viable food system (Stromberg, 2014). First generation plants will form more fertile soil, needed for growing plants of next generations. Residues of the farming activities could be composted and transformed into a soil-like substrate. (Kozyrovska et al., 2006).

It is known that plants might have to grow in the middle of hostility, without oxygen and liquid water. They will also have limited sunlight. Conditions will be adverse, so the priority is to

grow plants that are resistant to diseases and with a lower demand of sunlight. It is important to avoid using hormones or pesticides to grow the plants. According with recent researches in the International Space Station, plants can grow in microgravity. However, scientists are still not sure of how lower gravity may affect the regular growth and development of plants; so the growth of plants to be farmed in the future missions to Mars must not strictly depend on gravity. It is fundamental to grow plants that fruit quickly in order to get results in a short period of time. It is unsustainable to grow plants that take a long time to produce fresh food. As a productivity aspect, it is also important to consider those plants that need less space to grow and less human attention.

Mars' surface receives 43% of the sunlight our planet receives and even that limited amount of light may be reduced more by pressurized greenhouses enclosures (Moskowitz, 2013). Even though Miller (1999) explains that with a 43% is enough to make photosynthesis possible, other authors think that we should not be so optimistic. To complete the supply of light the plants would need, the use of a complementary and artificial illumination system is vital. According to Moskowitz (2013), NASA has been studying the use of LED technology to provide plants the wavelengths of light they need to be more efficient; the problem is that supplying LED light requires a significant amount of power. It is also important to mention that the lifetime of the LED devices is between 5 and 10 years (Salotti, 2002). Another real challenge is low pressure. Researchers are studying if plants can survive in lower pressure than in Earth; because the more pressure inside the greenhouse, the more massive the greenhouse must be to contain it (Moskowitz, 2013). The same author claims that Mars does not have a protective atmosphere like the Earth does, so particles from the space may reach the surface and damage both people and plants. The solution to this issue might be the construction of a shield as a protective system.

We also have to consider the idea of growing plants in as a reduced atmospheric pressure as possible because the greenhouse must hold up in a place where the atmospheric pressures are less than one percent of Earth normal pressure. If the interior pressure is also very low, the greenhouses will be easier to construct and operate. Low pressure may also have a positive impact on food storage, as it eliminates the hormone ethylene (NASA, 2004). The average temperature in Mars is -60°C or -76°F, so an additional heating system will be required to make farming possible (Miller, 1999). "The structure of the greenhouse and the materials that sheath them must be resistant to endure the inner pressure of the greenhouse, considering that the ambient pressure is 1/100 of terrestrial atmosphere. The filmy sheathing materials should be optically transparent to admit solar radiation indispensable for human life and photosynthesis of plants, but opaque to the harmful ultraviolet part of the solar radiation" (Yamashita et al., 2009). Finally, plants will also need water and pure water might potentially be made by melting Martian surface ice (Stromberg, 2014).

First residents of Mars and the members of the first pioneering Martian societies won't have the time required to conduct vegetable growing experiments that will lead to the knowledge needed for Mars farming. From maintaining all the systems working correctly to performing other experiments related to the mission priorities, there will be a lot of activities that will demand their time. That's why previous experiments on Earth must be conducted in order to give the future Martian farmers all the information they need.

Most representative challenges

Even though Mars has many similarities with the Earth, we should be realistic. There are many aspects that may be an issue as we try to construct a growth system for plants. Stromberg (2014) explained that a recent experiment carried out by Curiosity indicated the presence perchlorates in Martian soil. This toxic chemicals are not present in the Mars regolith simulant and their effect on plants has not been studied yet; but a bacteria capable to degrade perchlorate salts has been discovered in Atacama, Chile (Pietramellara et al., 2014). Stromberg claims that even if experiments showed that plants may sprout and grow in Mars regolith, that does not mean that is possible to produce enough food to feed all the crew members for a long period of time. Miller (1999) calculates that each crew member will need a supply of approximately 2800 calories per day. The composition of atmosphere is also a serious problem: it is about 100 times thinner than Earth's and it is 95.32% carbon dioxide (Sharp, 2012). In addition to that, we still do not know exactly the effects of Mars' reduced gravity on plants and we have not develop the technology we need to produce liquid water from Martian ice. The conclusion we can get from all these statements is that there is still a lot to be investigated in the mentioned fields.

Materials and method

The crew grew radish, yam and sweet potato in a simulated Mars-station environment, the Mars Desert Research Station (MDRS) in Utah. The main objective was to investigate the characteristics of growth and development of plants in Martian conditions to find out whether its production is possible or not. The first step in this experiment was the selection of the farming species. Three aspects were considered to make this selection: the nutritional facts of the product obtained to contribute to the good health of the crew members, the crop efficiency and the space needed by the crop. According to Zhukov (2014), the biological module in which the crew would be able grow plants would support many types of crops. Some of these corps are dry bean, lettuce, peanut, rice, soybean, wheat, potato, sweet potato, tomato, carrot and radish. We finally decided to experiment with two tubers (sweet potato and yam) and a fresh crop (radish). We considered that our investigation would be richer if we analyzed more than one type of sweet potato, that why we selected two types: orange skin sweet potato and white skin sweet potato. In the case of the radish, our objective was to compare the growth of the radish plant in three types of soil: nutrient-poor Earth soil, fertile Earth soil and Mars regolith simulant. The Mars regolith was manufactured by NASA and purchased from Orbitec.

Results

The experiment started on February 22nd, 2015 and lasted 35 days. In the case of the radish, 3 small pots were filled with nutrient-poor Earth soil, 3 pots were filled with fertile Earth soil and the last 3 pots were filled with Mars regolith simulant. Two seeds were positioned in each pot. All the pots were placed in a tent with LED illumination and ventilation. The samples never had contact with the sun light and the LED light was turn on 10 hours per day. All the pots

were watered twice a day: once at 10 a.m. and once at 9:00 p.m. We used demineralized water for the Mars regolith samples in order to avoid any variation in the results due to the minerals, bacteria or nutrients that are present in tap water. The evaluation was based on germination and stem length. We made observations twice a day, before we watered the plants. We could see the first evidences of the plants' growth in the third day of the experiment both in the fertile Earth soil and in the Mars regolith. In the fourth day, same thing happened to the plants in nutrient-poor Earth soil. After two weeks, the plants growth in the Mars regolith was surprising: only one of the six seeds died and the plants developed faster than in the nutrient-poor Earth soil. Five crops germinated and went through the first stages of plants development for a period of 35 days.

In the case of the sweet potatoes and yam, 4 samples of each type of tuber were analyzed. To prepare the samples, we took 3 units of each type of tuber and washed them well. Then we cut in half one of each type, that gives us 4 samples per type (2 whole tubers and 2 halves of each type). After that, we filled jars with water and placed one sample per jar, half in/half out, using toothpicks. The jar's opening was large enough to fit the tuber. All the whole tubers had contact with the water. In the case of the halves, one of each type had contact with the water and the other one did not. In the second case, the distance between the tuber and the water was approximately 1 centimeter. All the jars were placed in a tent with LED illumination and ventilation. The samples never had contact with the sun light and the LED light was turn on 10 hours per day. We measured daily the amount of water in the jar and we found out that it decreased day by day, it was absorbed by the tubers. After three days, small sprouts and green dots were visible. The growth was very slow, small branches began sprouting up after 22 days. The samples that did not have contact with the water looked dry and no sprouts were visible. After 35 days, it was easy to evaluate the growth of the samples. Yam potato grew faster than the other species and its branches were the longest, although its development was slower as compared to terrestrial conditions and that difference was very significant.

Discussion

In the case of the radish plants, 83.3% of the seeds planted in Mars regolith germinated and grew (Figure 1). The development of plants in Mars regolith was very similar to the development of plants in fertile Earth soil, plants in the Mars regolith even performed better than plants in the nutrient-poor Earth soil. In nutrient-poor soil, only 67% of the seeds germinated and grew and they germinated one day after the rest of the plants. Results were very promising, but further analysis of the regolith is suggested to confirm the absence of significant quantities of organic matter that may have had influence on the positive results of the experiment.

Conclusions

Missions to Mars must be self-sufficient and production of food for crew members will be a priority. Health and performance of crew members will depend on the food they will eat, this is why the right decision is to choose food combinations that contribute to a balanced diet according to their requirements. Since fresh food would provide the nutrients they will need, they will definitely have to learn how to grow plants in Mars using native soil. Plants will not just provide food, but also a cleaner air and will help them to have a better mood.

The results from the experiment in a simulated Mars-station environment show that radish plants are able to germinate and develop in a period of 35 days without the addition of any nutrient or fertilizer. The growth of the plants was even better than on nutrient-poor Earth soil, so cultivating radish in Mars is definitely promising. On the other hand, sweet potatoes and yam plants germination was slower than in normal Earth conditions. We assume that the lack of natural sun light was the reason, but further investigation on the subject is suggested. We also consider that the method we used might not be the best in this situation, so we suggest to use tuber seeds in future experiments. Yam development was the fastest and the orange skin sweet potato development was the slowest. The difference between the plant growth in Mars simulation conditions and the plant growth in terrestrial conditions was significant. With this results, we conclude that the method we use was not the more effective in Mars conditions. The water and the sun light may have an important contribution to the growth of plants, therefore it must be ensured that these two resources are held in the required amounts.

There are still many challenges related to Mars farming: the possible presence of toxic chemicals in Martian soil and the uncertainty of its productivity, the composition of atmosphere, the unknown effects of Mars' reduced gravity on plants and the lack of liquid water. There is still a lot to be investigated in the mentioned fields, Mars farming will be almost impossible if we can't find solution to these problems. Although there is still a lot to be investigated, we should feel optimistic and recognize all the accomplishments we have achieved to make possible the future Mars expeditions. Curiosity is exploring Mars' surface and many experiments show that farming in Mars may be viable under some controlled conditions.

The stem length gives us information about the stage of the plants' development. After 35 days, the average stem length of the Fertile Earth soil plants was 7.5 cm, slightly higher the average stem length of the Mars regolith plants (7.1 cm). However, Mars regolith plants performed better than nutrient-poor Earth soil plants. (Figure 2)

In the case of the sweet potatoes and yams, the germination and development of the plants were slower than in normal Earth conditions. We assume that the lack of natural sun light was the reason, but further investigation on the subject is suggested. Yam development was the fastest, an average of six sprouts per sample appeared in the first two weeks. On the other hand, orange skin sweet potato development was not good; the average of sprouts was only 2 per sample. Water was also important, as the samples that did not have contact with it became dry and did not germinate. The difference between the plant growth in Mars simulation conditions and the plant growth in terrestrial conditions was very significant. With this results, we conclude that the method we used to plant the tubers was not the more effective in Mars conditions. (Figure 3)

We found out that the average percentage of water absorption was not considerably different between the tubers analyzed, in all the samples these values were from 10% to 14.5%. (Figure 4).

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Appendices

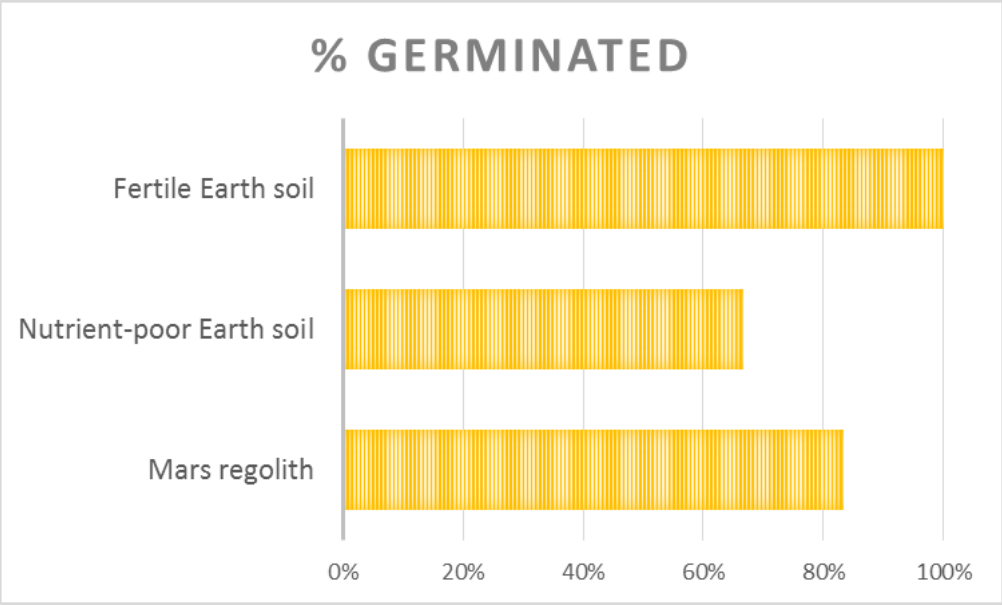


Figure 1. Percentage of plants that germinated and lived after 35 days per type of soil used. We considered the performance of all the samples after 35 days of experiment. There were 6 seeds analyzed in each type of soil.

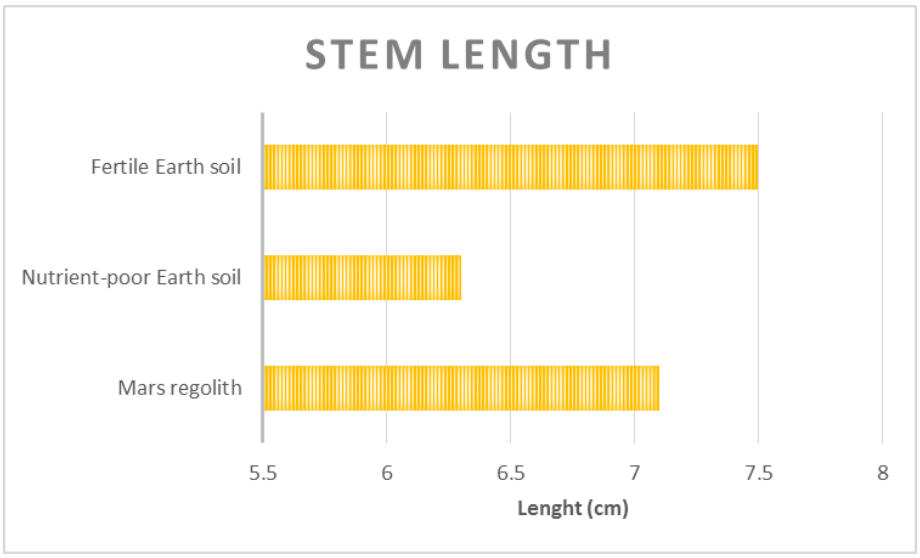


Figure 2. Average stem length of the plants after 35 days per type of soil used. We considered the performance of all the samples after 35 days of experiment.

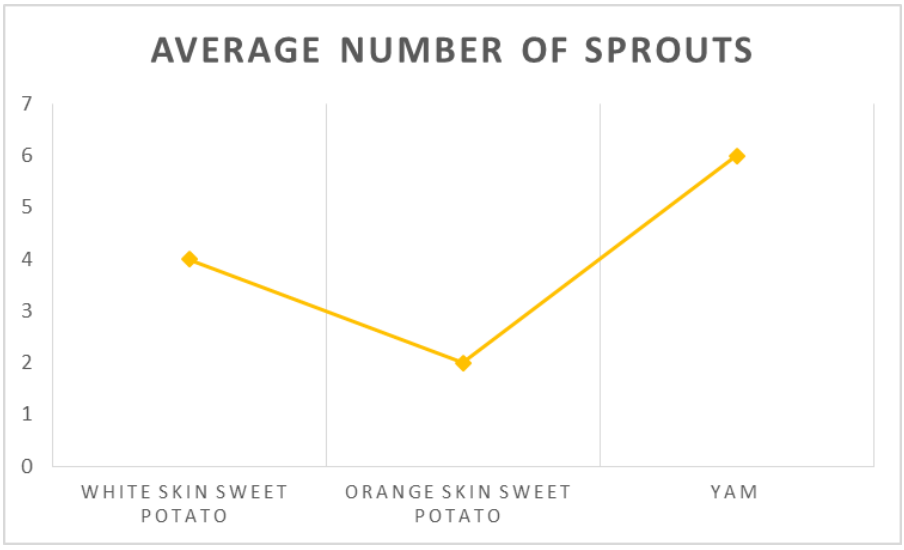


Figure 3. Average number of sprouts after 35 days per type of tuber. We considered the performance of all the samples after 35 days of experiment. There were 4 samples analyzed per each type of tuber.

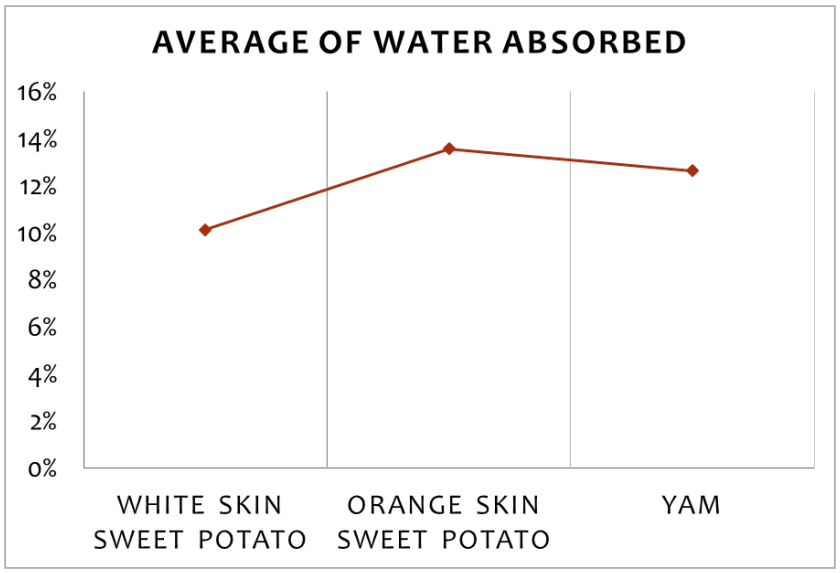


Figure 4. Average of water absorbed after 35 days per type of tuber. We considered the performance of all the samples after 35 days of experiment. There were 4 samples analyzed per each type of tuber.