<u>Next Stop Mars Explorers:</u> Charlotte Gannon, Isabella Leao, Katie May, and Robin Murphy
Team ID 11290

<u>Mars Regolith Project</u> - Testing Mars Global Simulant MGS-1 Enhancements including a Novel Water/Nutrient Delivery System for Growing Crops for a Mission to Mars

<u>Abstract</u>

Finding a way to grow crops in Mars Regolith is important in terms of sustaining future life on Mars. It is hypothesized that enhancing Mars Regolith with a polyacrylamide superabsorbent polymer (PAM SAP) and organic nutrients will enable crops to grow more successfully. The experiment covered three planting stages. In stage I, triplicate planting of eight radish seeds were grown in seven different groups. Two control groups with Earth soil (C1) and Mars Regolith (C2), and five Mars Regolith experimental variable groups with enhancements: fertilizer (V1), organic nutrients (V2), PAM SAP (V3), fertilizer PAM SAP (V4), and organic nutrient PAM SAP (V5). Stage II kept all groups constant while adding 25% volume of matured compost to enhance growth. In planting stage III, arugula, radish, chard, lettuce, and kale were grown in the most successful variable from Stage II (V5). The most significant finding in this study was that V5, PAM SAP enhanced with organic nutrients, produced the most radish plants compared to other groups. While the V5 plants did not have the greatest average height at 2.8 cm compared to V3 at 3.7 cm, it had the most plants grown in total (12), 42% more than the Earth soil control. In stage III, the radish plants experienced the most growth (8 plants), 37.5% more than the next successful crop, arugula. The implications of this study include the development of a novel nutrient and water delivery system for a reliable food source to help sustain life on Mars.

<u>Introduction</u>

<u>Aim:</u> The goal of this study is to determine which enhancements regarding water/nutrient delivery systems can improve and maximize the quality and quantity of a radish crop grown in Mars Regolith, to have the same or better quality as a crop grown in Earth Soil. Specifically, the ultimate goal is to determine the effectiveness of a superabsorbent polyacrylamide polymer, SAP PAM, absorbed with different substances as a water and nutrient delivery system for the Mars Regolith to help crops, such as radishes, grow. The novel nutrients to be tested include fruit peels and fruit peel extract.

<u>Why Mars?</u> Mars is an important planet to focus on because of its resources. There is liquid water underground on Mars, so if one could drill into the ground, there could be life in the water, which would allow us to find more about the biochemical structure of life beyond Earth. This is important in discovering more about the ways in which we can sustain life on Mars, however, for the purposes of our experiment, this is valuable as the water available in the core of Mars can be extremely useful to the growth of crops in Mars Regolith.

<u>Hypothesis/Driving Research Question</u>: It is hypothesized that the superabsorbent polyacrylamide polymer (SAP PAM), which holds and releases water over time, will aid in the water distribution to the Regolith over the growth period and therefore will enhance growth. The water delivery from the SAP PAM will be improved by the high content of salts present in the Mars Regolith, as salt helps in water release from the SAP PAM. Furthermore, using dried fruit peels and fruit peel extract with a high nutrient density will provide a natural and sustainable source of nutrients for the crops, and those plants will grow as much or better as the ones with traditional chemical fertilizer. The ultimate goal would be to grow crops that produce nutrient rich crops that may also be recycled into the Regolith.

<u>Review of Literature</u>

Before missions studying if human life can survive on Mars, scientists developed artificial soil mixtures that mimic materials found on Mars and evaluated them to see how fertile the soil could be (Flurry, et al., 2020). The scientists used data taken from NASA's surface samples to develop the stimulants. They made sure to use materials such as mixtures of soil, clay minerals, and salts that are similar to what you would find if you were to take a sample from Mars' surface. Although Mars has the majority of plant essential nutrients, like nitrogen and potassium, the plants are unable to just pull it out of the soil. Furthermore, the nutrients could either be in very low quantities or high concentrations, both of which harms the plant. Some mixtures they have come across so far include rinsing the soil or adding bacteria or fungi to it, as they tend to support plants in stressful conditions.

There have been many studies in which scientists have attempted to grow crops usings Mars simulant soil. The first large-scale controlled experiment to determine the possibility of growing plants in Mars and moon soil simulants conveyed the fact that plants can grow on Mars and moon soil simulants for 50 days without the addition of extra nutrients (Wamelink, et al., 2014). Growth on the Mars simulant was better than both the moon and the control soils. Specifically, the crops tomato, wheat, and cress, and the green manure species field mustard performed particularly well in the experiment. Thus, the results show that Mars soil simulants have the potential to grow successful crops, yet there are still questions about simulants' water carrying capacity and other physical properties. This demonstrates the need for additional research.

In another crop study, a group of undergraduate students and researchers attempted to see which types of crops would be able to grow in Mars Stimulant soil for future Mars colonists (Cartier et al., 2018). They grew each crop in the stimulant soil but also in Mars level light conditions, thereby creating a more Mars-like environment. The scientists found that kale, sweet potatoes, and certain lettuces grew very easily, even tasting no different than if they were grown on Earth. The differences in stimulant soil compared to Earth is that it had double the iron oxides as Earth soil, and also the Earth soil is much more organic.

In a similar study, researchers tested ten different seeds growing in lunar and martian regolith simulant soil in order to determine which crops would have the most success growing on the Moon and Mars (Wamelink, et al., 2019). In order to test whether crops can grow or not, which would be much healthier compared to current foods provided for astronauts, analyzed the control group of Earth soil, and the experimental groups of Mars and Moon simulant soil. After planting ten different crops of garden cress, rocket, tomato, radish, rye, quinoa, spinach, chives, pea and leek, scientists discovered that every plant except spinach was able to grow, and the addition of organic matter from their previous harvest enhanced this growth. Radish, rye and cress were most successful. Ultimately, this article helped our project in determining which kind of seeds would be best to try to plant in our own Mars Regolith, and points to organic biomass's usability to enrich plant development.

Another team of scientists tested the ability of crops to grow in Mars-like soil (Romero et al., 2020). Their "simulant" soil used to complete the study was made up of different rock particles mixed in proportions that match a rover's analyses of typical Martian soil. In an attempt to improve the crops, the team tried to infuse the Mars soil with nitrogen-rich human urine. Tomatoes, garlic, spinach, basil, kale, lettuce, rocket, onion and radishes were crops that were successful, despite the fact that the quality of harvests varied. In contrast, however, potatoes struggled as they prefer a much more loose soil. Overall, the team of researchers found that the key to success with farming on Mars may be to grow lower yield crops.

Enhancing Mars soil has been a goal of scientists as well. It was determined that a biofertilizer made from Alfalfa plants and desalinated briny water using marine cyanobacterium *Synechococcus sp* can be used to enhance Mars soil (Kasiviswanathan et al., 2022). Mars soil is low in nutrient content and high in salinity which hinders its ability to hold water for growing food crops. Its soil is also full of sulfates and perchlorates, which are detrimental to plant growth. Therefore, scientists discovered that these factors can be mitigated by using alfalfa plants that could grow in bare basaltic regolith simulant soil. After treating the soil with 100 mg of powdered Alfalfa plants and watering the plants with desalinated water (filtered using porous basaltic type volcanic rocks), scientists evaluated the growth production of turnips, radish, and lettuce plants. Ultimately, they found that this combination was most effective in producing crops.

Rationale:

Martian Global Simulant Regolith, MGS-1, is low in nutrient content, yet high in salinity, including a large amount of sulfates and perchlorates. Both of these factors contribute to the detrimental effects that Mars Regolith has on plant growth, and hinders its ability to hold water. Therefore, in order to mitigate these effects, superabsorbent polymer (SAP) beads made of crosslinked polyacrylamide (PAM) that are able to hold water and slowly release it throughout the soil will be tested. A novel nutrient enhancement consisting of fruit peels, that will allow crops to robustly continue their stages of development, will also be tested.

Both Banana and orange peels add nutrients and nitrogen to the soil as they decompose. In particular, banana peels are effective as a natural fertilizer, they rot quickly once buried where they release a rich amount of important nutrients like potassium, calcium, sulfur, phosphorus, magnesium, and sodium. Orange peels contain d-Limonene, which is a natural chemical that can keep away harmful bugs or aphids. Since Mars has been shown to have insects this may be an important feature (Romoser, 2019). Orange peels are also high in nitrogen, sulfur, magnesium, calcium and other nutrients that can give plants the nutrients they need to grow. Both banana and orange peels would therefore be effective for enhancing the growth of crops. In terms of our crop choice, the radish is a fast growing and nutritious root crop. Nutritional benefits include high fiber, calcium, and potassium. Radishes are also rich in Vitamins E, A, C, and B6. Furthermore, they are fast growing and ready to eat in as little as 4 weeks. They also do not require as much water as some other plants in order to grow.

Methods

I. ***Phase I Variables and Control:***

Independent variable - *Mars Regolith enhancements (nutrient sources and water/nutrient delivery method)*
Dependent variable - *crop growth (number of plants germinating in each pot, how fast and how tall)*
Control Group for Phase I *- Earth soil without enhancements (water only)*
-Mars Regolith without enhancements (water only)

Variable Group 1 for Phase I *- Mars Regolith with fertilizer (variable 1)*
- Mars Regolith with fruit peel (variable 2)

Variable Group 2 for Phase I *- Mars Regolith with water PAM SAP delivery system (variable 3)*
- Mars Regolith with fertilizer PAM SAP delivery system (variable 4)
- Mars Regolith with fruit peel extract PAM SAP delivery system (variable 5)

Note: *Variable Group 1 will also serve as a control for Group 2, to determine the effectiveness of the novel water/nutrient delivery system.*

Controlled variables (what will be held constant) for Phase I: *planting location, amount of light; amount and type of Mars simulant Regolith; size and type of planting container (peat boxes and planting boxes); amount of water for all plants; amount of the PAM SAP delivery method for Group 2.*

Note:

*For **Phase II**, the same variables in Phase 1 were tested, except with a 75/25 volume percent Mars Regolith/compost base instead of just Mars Regolith alone. Only radishes were again planted.*

*For **Phase III**, variable 5 (the most successful Mars Regolith enhanced variable from Part II) was used for 5 different crops, including radishes. Since we wanted to test other crop growth compared to radishes, a crop we knew grew successfully in variable 5, radishes were considered the control, or standard for comparison.*

II. Experimental Design and Procedures

- ***Figure 1a.*** *Lighthouse Used for Phases I and II, from Carolina Biological, Item Number #159004*

https://www.carolina.com/wisconsin-fast-plants-supplies/plant-light-house-with-lightbulbs/159004.pr?question=greenhouse

  - The lighthouse has a light height that adjusts for all stages of the plant's life cycle. The inside is lined with reflective material, which provides more uniform growth for plants. The dimensions of the lighthouse are 24" H x 19" W x 18" D, and it uses two 15-W LED high intensity bulbs with a color temperature of 5,000 K.

- ***Figure 1b.*** *Sacred Heart Greenwich Greenhouse used for Phase III*

https://outdoorpersonia.com/recent-projects/custom-12x30-greenhouse-for-sacred-heart-school-in-greenwich-ct

- ***Figure 2a.*** A sample of the PAM SAP, made by adding 225 ml of deionized water to 30 ml of PAM SAP beads.

- **Figure 2b**. Dehydrated and ground fruit peels shown below, made with 3 banana peels and 2 orange peels, dried for 12 hours in a desiccator and ground at high speed for 60 seconds. Fruit peel extract in PAM SAP was made by soaking 75 ml of peels in 225 ml of water, straining after 24 hours, and then soaking this solution in 30 ml of PAM SAP beads.

- ***Schedule:***

  - *Overall Growth period will be from 9/26-11/18*
  - *Preliminary gathering and setup of materials occurred during the week of 9/19:*
    - *Dehydrating and grinding fruit peels*
    - *Putting water, fertilizer, and fruit peels into PAM SAP*
  - *Planting for Phase I occurred during the week of 9/26*
    - *To monitor growth, the group worked during class, which meets approximately every other day, to measure the number of plants in each pot and height of each plant (centimeters) in both our lab notebook and shared google doc.*
    - *Measurements were made throughout all three phases until the end of the grow period on 11/18.*
    - *Watering occurred daily, at first 30 ml per day per pot, increased after week 1 to 60 ml per day per pot after the Mars Regolith pots appeared too dry in week 1.*

- ***Planting Design, Phase I:***
  - ***8 radish seeds** were used **per triplicate planting** for each control and variable.*
  - ***Controls and Variables for Phase 1:***
    - ***Control Group.***
      - *Earth soil with water (control 1)*
        - *60 mL Earth soil in each pot*
      - *Mars Regolith with water (control 2)*
        - *60 mL Mars Regolith in each pot*

  ****Variable Group I. Mars MGS-1 Regolith Simulant with enhancements***
      - *Mars Regolith with fertilizer (variable 1)*
        - *60 mL Mars Regolith; 15 mL fertilizer solution, made according to directions on Miracle Gro bottle (20 drops per 946 ml water)*
      - *Mars Regolith with fruit pee**l** (variable 2)*
        - *45 mL Mars Regolith; 15 mL fruit peel (solid) for total of 60 ml soil*

****Variable Group II. Mars MGS-1 Regolith Simulant with enhancements using a novel delivery system***

- *Mars Regolith with water PAM SAP delivery system (variable 3)*
  - *45 mL Mars Regolith; 15 mL PAM SAP with water for total of 60 ml soil*
- *Mars Regolith with fertilizer SAP PAM delivery system (variable 4)*
  - *45 mL Mars Regolith; 15 mL PAM SAP with fertilizer solution for total of 60 ml soil*
- *Mars Regolith with fruit peel extract PAM SAP delivery system (variable 5)*
  - *45 mL Mars Regolith; 15 mL PAM SAM with fruit peel extract for total of 60 ml soil*

Note: *For* ***Phase II,*** *the same variables in Phase 1 were tested, except with a 75/25 volume percent Mars/compost base instead of just Mars Regolith alone. Only radishes were again planted.*
For ***Phase III****, variable 5 (the most successful Mars Regolith enhanced variable) was used for 5 different crops: radishes, arugula, kale, lettuce, and chard.*

- ***Before the growth period, nutrient levels for the compost were measured.***
  - *Nutrient levels for the compost were measured using RapidTest Soil Nutrient Test Kit.*

  - ***Planting Design, Phase II.***
    - *All soil enhancements and variables kept the same as Phase I*
    - *Change in soil base composition: 75% by volume Mars soil and 25% matured compost soil*
    - ***Control Group***
      - *Earth soil and compost* with water (control 1)*
      - *Mars Regolith and compost with water (control 2)*
    - ***Variable Group I. Mars MGS-1 Regolith Simulant with enhancements (and controls)***
      - *Mars Regolith and compost with fertilizer (variable 1)*
      - *Mars Regolith and compost with fruit pee**l** (variable 2)*
    - ***Variable Group II. Mars MGS-1 Regolith Simulant with enhancements using a novel delivery system***
      - *Mars Regolith and compost with water PAM SAP delivery system (variable 3)*
      - *Mars Regolith and compost with fertilizer PAM SAP delivery system (variable 4)*
      - *Mars Regolith and compost with fruit peel extract PAM SAP delivery system (variable 5)*

  - ***Planting Design, Phase III.***
    - *Testing Mars Regolith and compost with fruit peel extract PAM SAP delivery system (variable 5) with varied plant types.*
      - *Soil base composition: 75% by volume Mars soil and 25% matured compost soil*
      - *Plant types: radish, arugula, chard, lettuce, kale*
      - *Control is the radish plants since we knew it experienced successful growth in Phase II, and other plant crops were being compared to it.*

****Information on compost used:*** *The compost was obtained from the school's compost bin. It consists of greens: fruits and vegetables, coffee grounds, and other meatless scraps from the school's dining halls. The other components of the compost are browns: dead leaves, shredded tree branches, twigs, mulch. The final ingredient is water. These items are separated into three separate bins, one containing the greens, one containing the browns, and the third one containing the combination of the two. The ratio of the compost is 30 parts brown to 1 part green by weight. The compost is then mixed* *with an auger every two weeks. Finally, it is mixed in with other compost and soil and left to degrade for about two years. The compost we used was two-year old school-generated nutrient-rich (in terms of potassium and nitrogen) compost. When testing nutrient levels using a soil test kit, the nitrogen was adequate, potassium was sufficient, and phosphorus was deficient.*

- ***Recordkeeping:*** *To keep accurate records, we will maintain a detailed lab notebook and also document results in our online shared Google document.*
- ***Safety and COVID-19:*** *At school we are using masks, gloves and goggles while handling the Mars soil, which corresponds to safety protocols. If there is a COVID-19 disruption, we will have remote cameras on our plants to document and record growth.*

- ***Tables outlining the specific grow pot setup (including controls):***

Table 1. Experimental Design for Phase I:

WITHOUT PAM SAP POLYMER BEADS	**Soil composition**	**8 seeds/pot in triplicate for a total of 24 seeds per control and variable**
Control 1	Earth soil	Radish
Control 2	Mars Regolith	Radish
Experimental Variable 1	Mars Regolith with fertilizer	Radish
Experimental Variable 2	Mars Regolith with fruit peel	Radish

WITH PAM SAP POLYMER BEADS	**Soil composition/Pot**	**8 seeds/pot in triplicate for a total of 24 seeds per variable**
Experimental Variable 3	Mars Regolith with water SAP PAM beads	Radish
Experimental Variable 4	Mars Regolith with fertilizer SAP PAM beads	Radish
Experimental Variable 5	Mars Regolith with fruit peel SAP PAM beads	Radish

Table 2. Experimental Design for Phase II:

WITHOUT PAM SAP POLYMER BEADS	**Soil composition**	**8 seeds/pot in triplicate for a total of 24 seeds per control and variable**
Control 1	Earth/Compost mix (75/25)	Radish
Control 2	Mars Regolith/Compost (75/25)	Radish
Experimental Variable 1	Mars Regolith/Compost with fertilizer	Radish
Experimental Variable 2	Mars Regolith/Compost with fruit peel	Radish

WITH PAM SAP POLYMER BEADS	**Soil composition/Pot**	**8 seeds/pot in triplicate for a total of 24 seeds per variable**
Experimental Variable 3	Mars Regolith/Compost with water SAP PAM beads	Radish
Experimental Variable 4	Mars Regolith/Compost with fertilizer SAP PAM beads	Radish
Experimental Variable 5	Mars Regolith/Compost with fruit peel SAP PAM beads	Radish

<u>Experimental Design for Phase 3: In Greenhouse on School Campus, to determine how other crops compare to radish growth</u>

Table 3. Experimental Design for Phase III:

Plant Type	**Number of Seeds per pot, duplicate pots for each control and variable**	**Soil Type:**
Radish (Control)	25	PAM SAP with fruit peel extract
Arugula	25	PAM SAP with fruit peel extract
Kale	25	PAM SAP with fruit peel extract
Chard	25	PAM SAP with fruit peel extract
Lettuce	25	PAM SAP with fruit peel extract

Results

Planting Data, Phase I

Starting Date: 9/28/2022

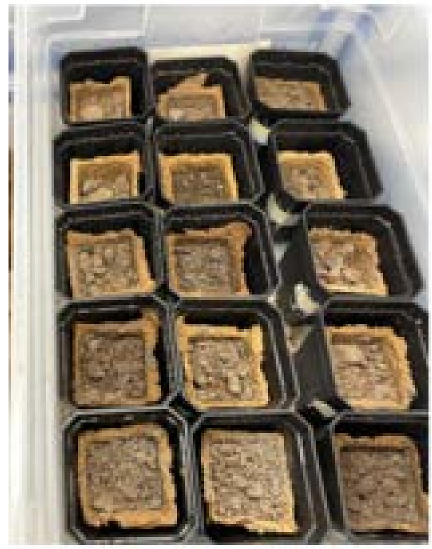


Figure 3. Phase I photos taken after 1 week on October 4 (controls C1 and C2 on left and variables V1 - V5 on right). After 1 week, there were 3 plants in the Earth soil control, average height of 1.75 cm (photo on left). There was no growth in any of the 5 experimental variables (photo on right), even after 2 weeks.

Planting Data, Phase II

Starting Date: 10/20/2022

Data at end of Week 1: October 20-27 (Data taken: October 27, 2022)

Table 4. Experimental Data for Phase II End of Week 1:

Temperature	67.5 F	19.7 C
Humidity	61%	

Variable	**Number of plants**	**Average height (cm)**
Earth - C1	20	2.15
Mars - C2	4	1.63
Mars - V1	1	0.1
Mars - V2	1	0.2
Mars - V3	3	1.67

Mars - V4	5	1.24
Mars - V5	12	1.35

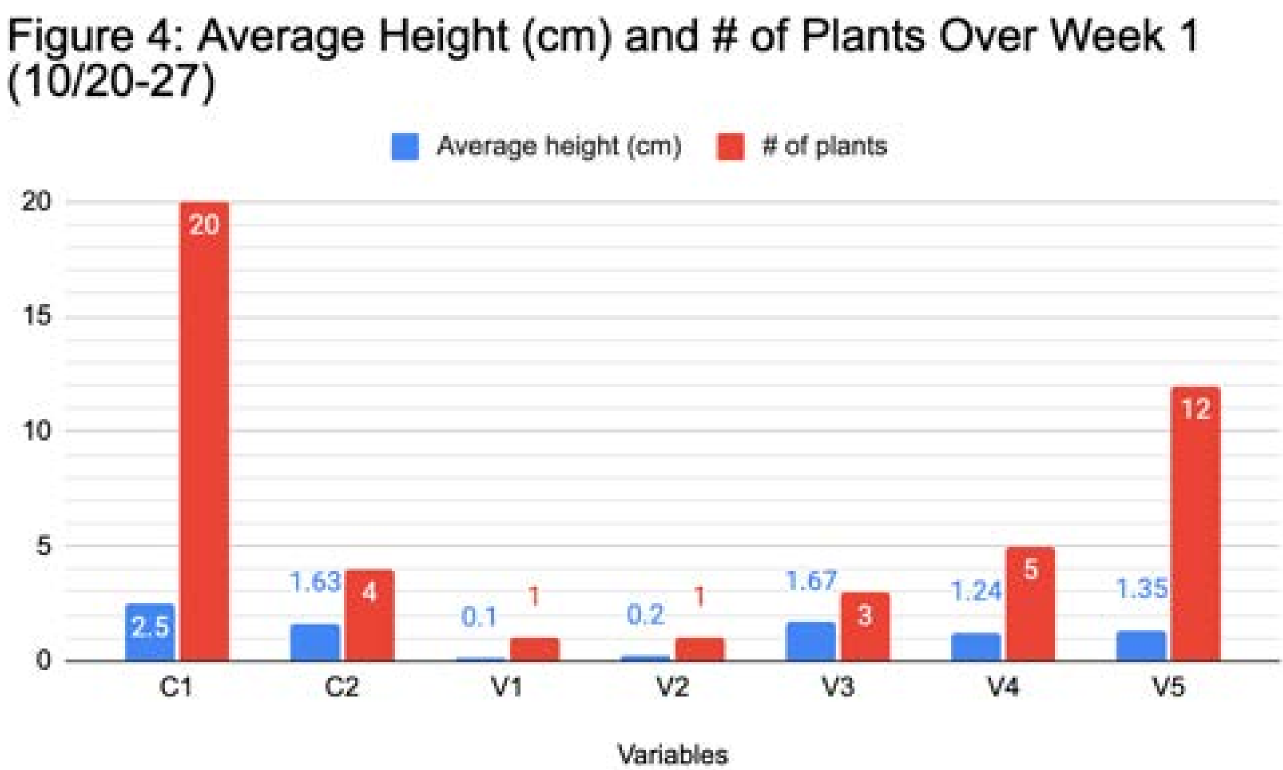


Figure 4. Plant height and number of plants for Phase II at the end of one week. Compared to the experimental groups, V5 with fruit peel PAM SAP, had the best plant growth in terms of number at 12 plants.

Figure 5. Phase II photo taken on October 27, after 7 days. On the right, the second row down is the Earth control group and has the most growth overall. V5 with fruit peel PAM SAP, which is the second column of plants to the left, has grown the most compared to other experimentals.

Phase II Data At end of week 2 - October 27 - November 3 (Data taken: November 3)

Table 5 Experimental Data for Phase II End of Week 2:

Temperature	82.1 F	27.83 C
Humidity	36 %	

Variable	**Number of plants**	**Average height (cm)**
Earth - C1	7*	7
Mars - C2	2	2
Mars - V1	-	-
Mars - V2	-	-
Mars - V3	3.7	3
Mars - V4	2.5	1
Mars - V5	2.8	12

*13 Earth control plants died from week 1 to week 2

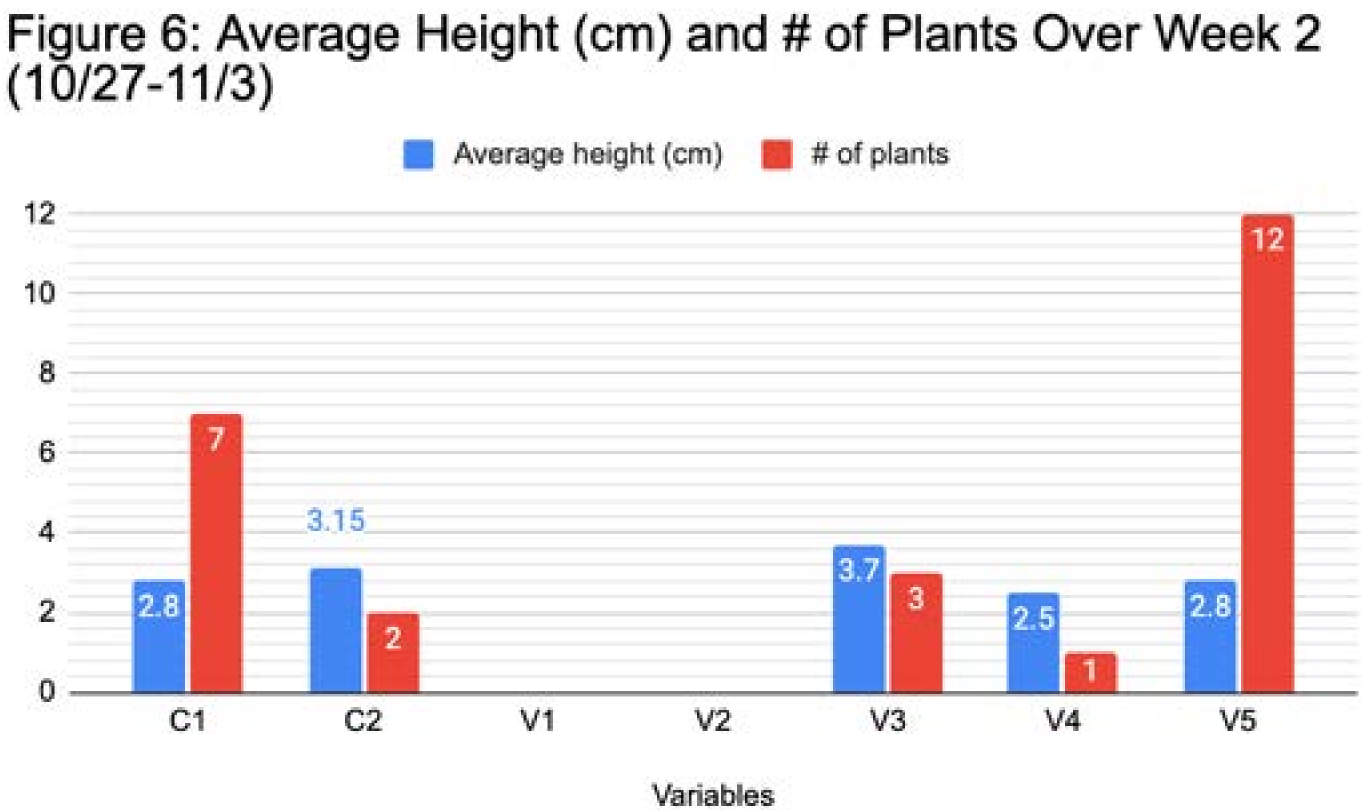


Figure 6. Plant height and number of plants for Phase II at the end of two weeks. Compared to the experimental groups, V5 with fruit peel SAP PAM, had the best plant growth.

V5 →

Figure 7. Phase II photo taken on November 1, after 1.5 weeks. V5, the Mars/compost variable with fruit peel PAM SAP is in the back row on the left, as indicated by the arrow. V5 had the best growth of all the variables.

Data for Phase II at end of week 3: November 3 - 9 (Data taken on November 9)

Table 6. Experimental Data for Phase II End of Week 3:

Temperature	79.1 F	26.17 C
Humidity	33%	

Variable	**Number of plants**	**Average height (cm)**
Earth - C1	-	-
Mars - C2	-	-
Mars - V1	-	-
Mars - V2	-	-
Mars - V3	-	-
Mars - V4	-	-
Mars - V5	3	3.0

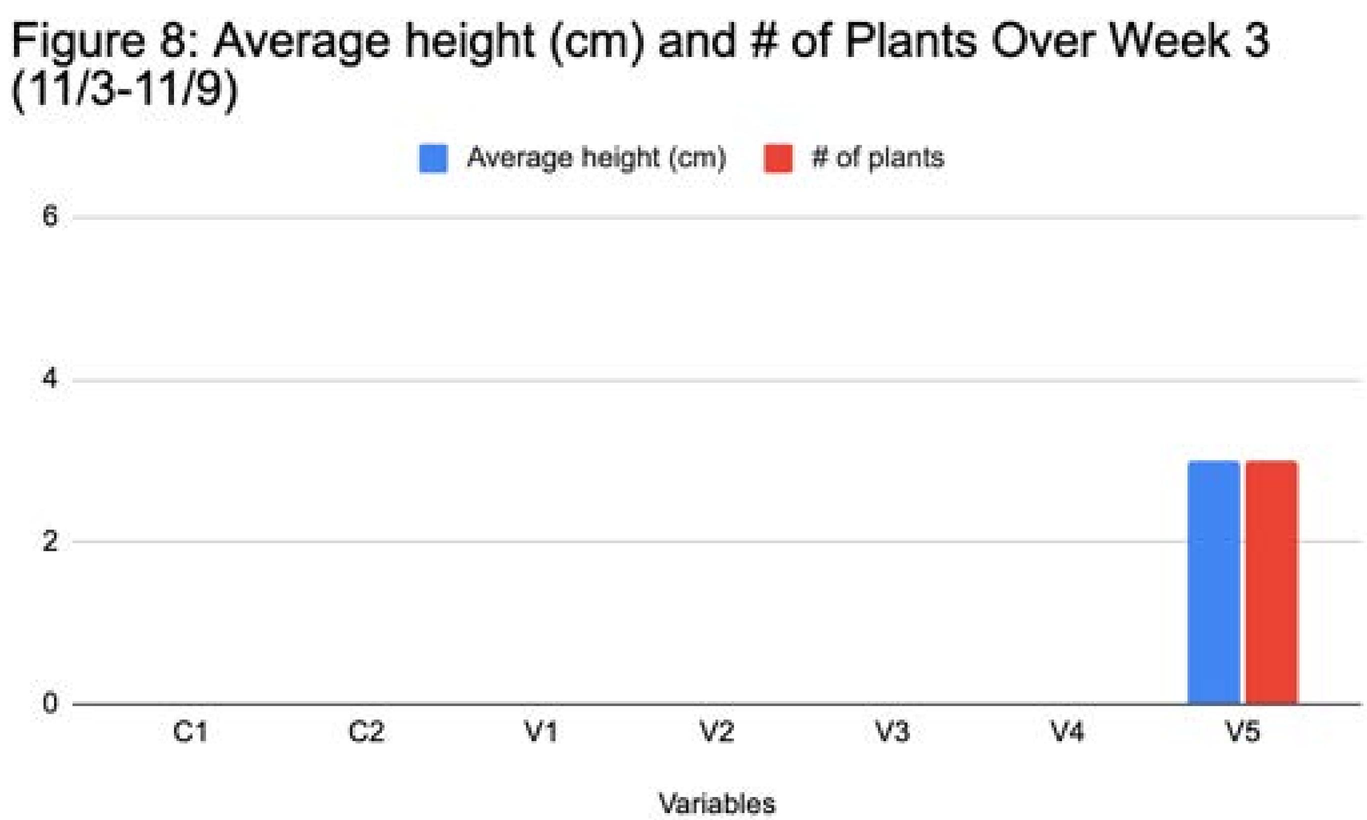


Figure 8. Plant height and number of plants for Phase II at the end of three weeks. The only viable radish plants were from Variable 5, the PAM SAP with fruit peel extract. Most plants had died off - only V5 remains.

Planting Data, Phase III

Starting Date: 11/4/2022

Data at end of Week 1 - November 4-11 (Data taken on November 11)

Table 8. Experimental Data for Phase III End of Week 1:

Plant Type	**Soil Type:**	**Number of Plants Growing**	**Average Height (cm)**
Radish	PAM SAP with fruit peel extract	4	0.75
Arugula	PAM SAP with fruit peel extract	2	0.5
Kale	PAM SAP with fruit peel extract	-	-
Chard	PAM SAP with fruit peel extract	-	-
Lettuce	PAM SAP with fruit peel extract	-	-

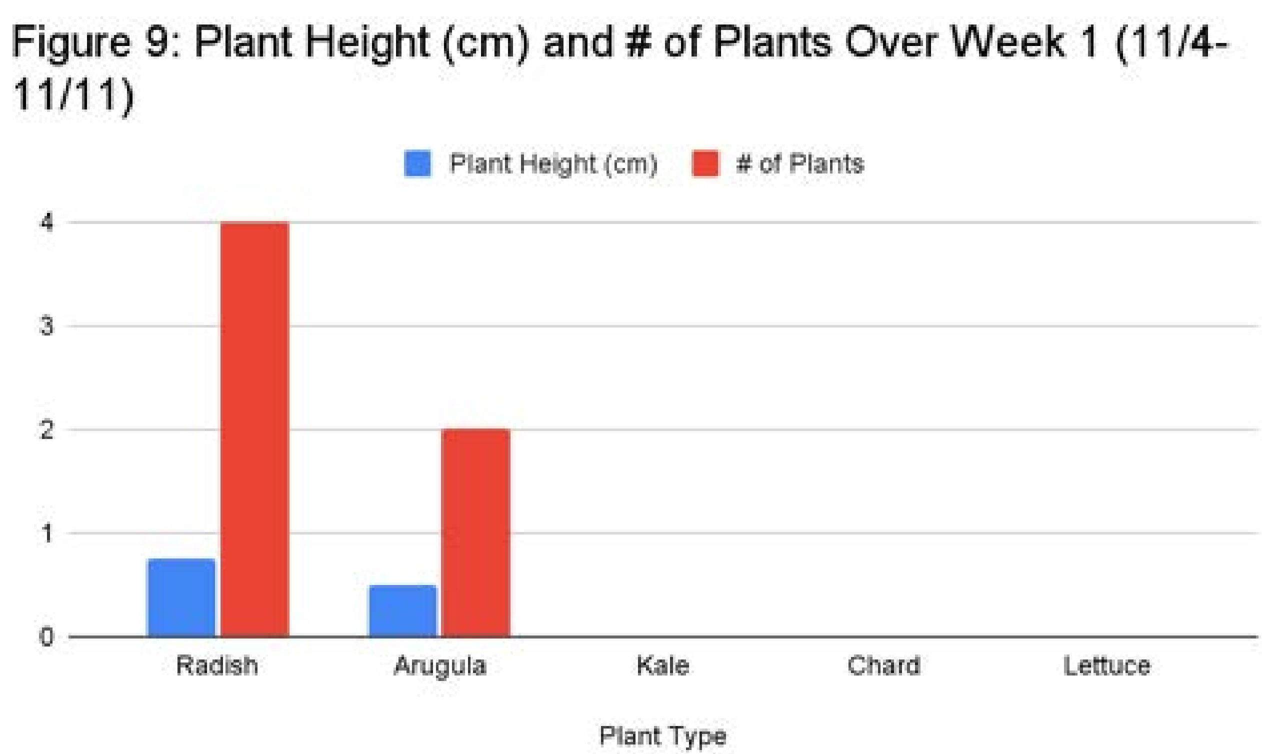
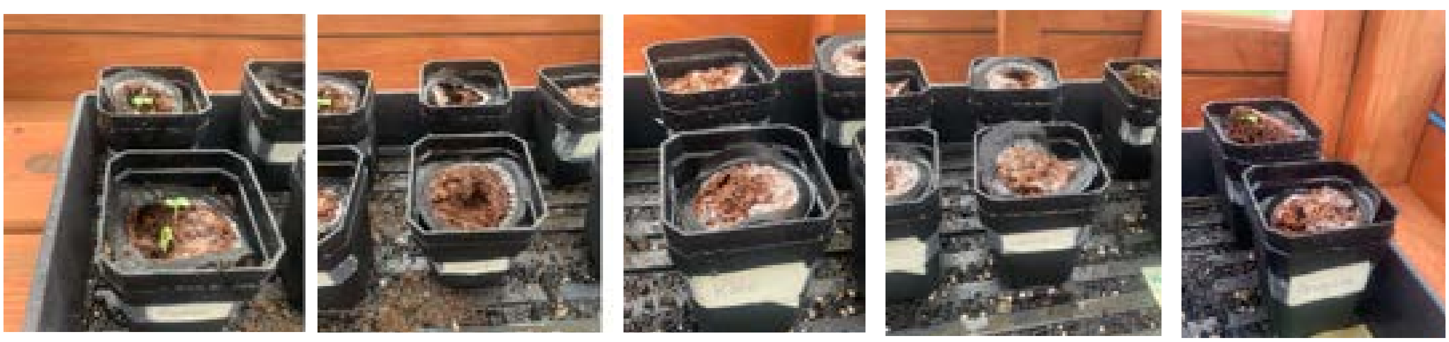


Figure 9. Plant height and number of plants for Phase III at the end of one week. The radishes grew the best with arugula as the second crop to grow in the PAM SAP with fruit peel extract.

Figure 10 - Phase III. Multiple crops were grown in the greenhouse on campus in the best soil variable from Phase II (V5). The soil used was Mars/Compost 75/25 mix with PAM SAP and fruit peel extract. Photo above taken on 11/4/22.



Radish	Chard	Kale	Lettuce	Arugula

Figure 11 - Phase III. After 1 week, out of the 5 crops, radishes on the far left, grew best in the Mars/Compost 75/25 mix with PAM SAP and fruit peel extract. Arugula, far right, was next in terms of success. **Photo taken on November 11, at the end of Week 1.**

Figure 12. Phase III plant growth in PAM SAP with fruit extract at the end of the growth period on November 18, after 2 weeks since planting. Radishes, far left, had the greatest number of plants and the best growth overall.

Phase III Data at end of Week 2, November 11-18 (Data taken on November 18)

Table 9. Experimental Data for Phase III at End of Week 2:

Plant Type	**Soil Type:**	**Number of Plants**	**Average Height (cm)**
Radish	PAM SAP with fruit peel extract	8	3.0
Arugula	PAM SAP with fruit peel extract	5	0.5
Kale	PAM SAP with fruit peel extract	-	-
Chard	PAM SAP with fruit peel extract	4	1.0
Lettuce	PAM SAP with fruit peel extract	2	0.5

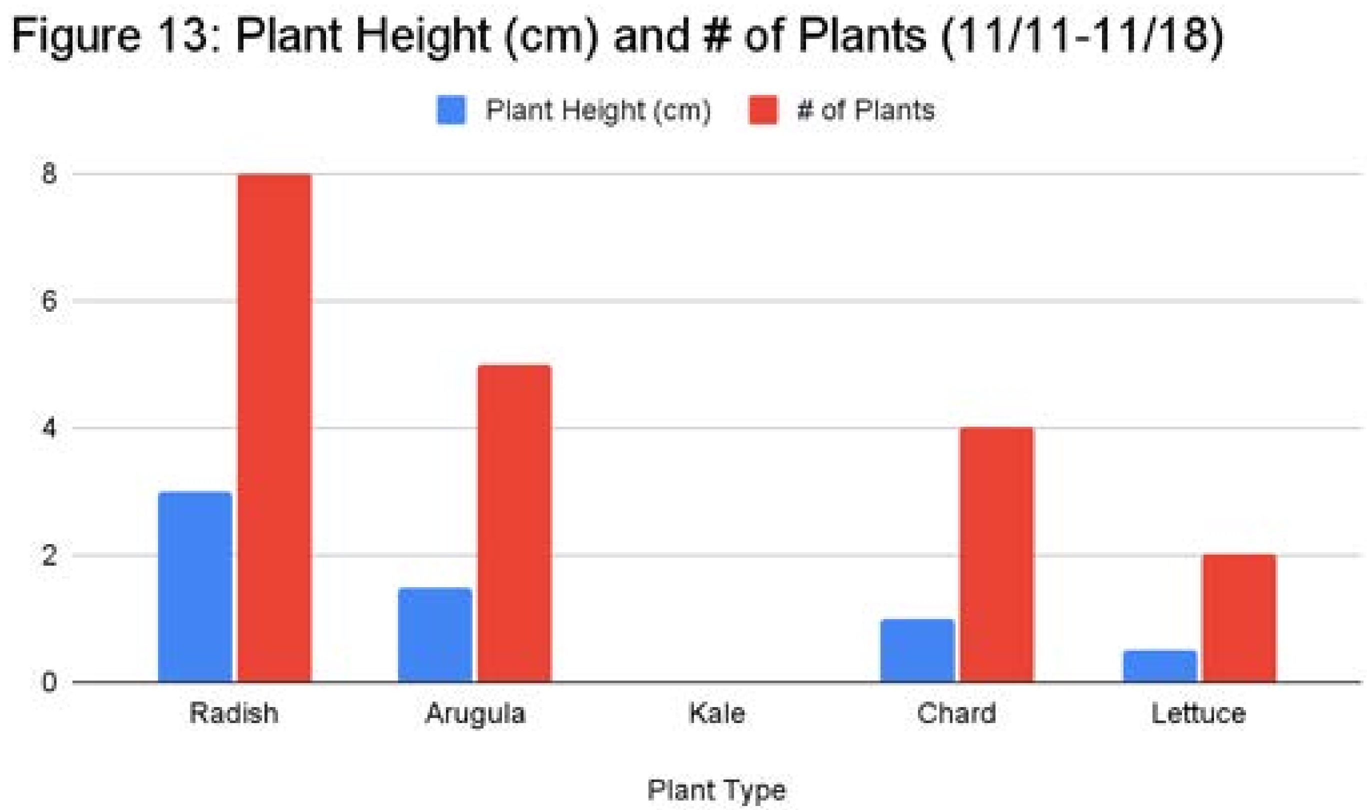


Figure 13. Plant height and number of plants for Phase III at the end of week 2 on 11/18. Radishes grew best, with arugula being the second best crop to grow in the PAM SAP with fruit peel extract.

Discussion for Phase I

In our first experimental attempt (Phase I) of planting radish seeds, our independent variables, including Mars Regolith enhancements such as fertilizer, fruit peels, and PAM SAP as a delivery system, were used to affect and improve plant growth. After 2 weeks, since we only had growth in the Earth soil control group (Figure 3), we attempted a second experimental design (Phase II) using a new 75/25 percent by volume soil base of Mars soil and matured compost. All other soil enhancement variables were kept the same. Throughout Phase II, we continued to use radish seeds to grow. In Phase III, we took the most successful soil mix, the Mars/compost mix with PAM SAP with fruit peel extract and planted different crops to see which would be the most successful. Radishes grew the most, thereby confirming our initial choice of the radish crop.

A challenge we faced, therefore, over the course of Phase I was that our initial radish plants in the Mars Regolith control, or any of the Mars Regolith enhancements, were not sprouting. Although our seeds in the Earth soil began to sprout, we did not see growth in our other pots (Figure 3). We believe that this problem was due to the fact that the Mars soil appeared significantly drier and more compacted than the Earth soil. Therefore, we increased the amount of water from 30 ml to 60 ml per pot per day to ensure they received the moisture they needed to grow. Since this did not improve growth in week 2, we decided we needed to make a change and thus, we began Phase II by adding two-year old school compost to the Mars Regolith, keeping all other conditions from Phase I the same. This change led to growth within several days.

The compost helped to add the necessary nutrients and reduced the compacted nature of the Mars Regolith. The new mix was 75/25 percent Mars Regolith/compost by volume.

To summarize, our plants in Phase I had a difficult time growing. Some plants, particularly those grown in Earth soil, were able to sprout a little, showing signs of greenery. However, we witnessed no growth in the plants grown in Mars Regolith, even with enhancements. We considered using a different greenhouse system for planting if we were to repeat this experiment because we hypothesized that the artificial light from our current setup was too powerful and generated too much heat. In the next round of planting (Phase II), we added compost to the Mars Regolith to enhance it. It worked well, producing growth in some of the variables, especially the one with fruit peel extract in PAM SAP. We were very encouraged by these results. In the last Phase of planting (Phase III), we did end up using the on-campus greenhouse to produce optimum results.

Discussion for Phase II, Week 1

Phase II involved using an enhanced Mars Regolith base. As previously mentioned, we created a 75/25 percent by volume Mars Regolith/compost mix. At the end of week one in Phase II (see Figure 4), not including the Earth soil, we found that there was the most growth in Variable 5: the Mars Regolith/compost mix with fruit peel extract in polyacrylamide super absorbent polymer (PAM SAP). This was an important finding and a trend that lasted throughout Phase II of the study. It is interesting to note that compared to the similar variable of fruit peel without the PAM SAP (V2), there was significantly more growth *with* the PAM SAP (V5). For example, the average growth with fruit peel extract alone without PAM SAP (V2) was 0.2 cm and the average growth in the fruit peel in PAM SAP variable (V5) was 1.35 cm, representing a 575 % increase in plant height. The number of plants in fruit peel alone without PAM SAP was 1 and the number for fruit peel with PAM SAP was 12, representing a 1100% increase in the number of plants.

It was realized that we need to retest some of our variables since the Mars/compost control alone (C2) had more growth in comparison to Mars/compost with fertilizer (V1) and with fruit peels (V2) (Figure 4). We would expect the Mars/compost soil mix with fruit peels (V2) and the Mars/compost soil mix with fertilizer (V1) to have more plant germination and growth than the Mars/compost control (C2), but it had less. Specifically, V2 had 0.2 cm growth and V1 had 0.1 cm growth, while C2 had 1.63 cm growth (see Figure 4). This data was inconsistent with what was expected, and requires further investigation.

Discussion for Phase II, Weeks 2 and 3

At the end of week two, the most growth occurred in Variable 5 again, with 12 plants and an average plant height of 2.8 cm (see Figure 6). Most significantly, while the average height of plants in V5 and the average height of plants in the Earth Soil Control Group (C1) remained the same, the number of plants in V5 exceeded the number of plants in C1 by 5 plants.

The plants in V1 and V2 at the end of 2 weeks were severely wilted. Therefore, they were non-viable and were not recorded in the data table (see Figure 6). Additionally, although V1 with fertilizer had seemed to be a promising solution for the Mars Regolith initially in week 1 of Phase II, as shown in Figure 4, over time the plants in V5 with PAM SAP and fruit peel extract had more long-term efficacy (see Figures 6 and 8). While the fertilizer and fruit peel extract variables do affect plant growth early on with immediate bursts of nutrients, the PAM SAP allows for a gradual release of nutrients, which is more sustainable for the plants in the long term. All in all, V5 with PAM SAP demonstrated the best results. At the end of week 3 in the Phase II planting session, V5 was the only viable option (see Figure 8).

Discussion for Phase III

In the final phase of the experiment, we wanted to see which crop grew the best in the most successful variable of PAM SAP with fruit peel extract (V5). Therefore, we planted radishes, arugula, kale, chard, and lettuce in this V5 variable soil mix. At the end of two weeks, we found that radishes had both the greatest number of plants grown at 8 plants, representing 37.5 % more than the next successful crop, arugula (see Figure 13). The radish plants also had the highest average plant height at 3 cm.

Conclusions

Our main plan was to use Mars Regolith enhanced with a **Polyacrylamide Super Absorbent Polymer or PAM SAP** to deliver water or water with nutrients over time to the radish plants. This polymer can readily absorb water and nutrients and then release them slowly over time. Originally, we thought that using just The PAM SAP in the Mars Regolith to deliver water and nutrients would stimulate plant growth, however, we found that this method was unsuccessful when using Mars Regolith alone, and we needed to supplement the Mars Regolith first. We needed to create a new Mars base soil, and then try our enhancements. Thus, we used our school's compost, that comes from the student and faculty dining rooms, and combined it with the Mars Regolith to create a base that was 75% Mars Regolith and 25% compost, by volume. After testing different combinations of our new Mars mix with fertilizer, fruit peels, and PAM SAP, we found that after two weeks of plant growth, the most successful combination was the **fruit peel extract in the PAM SAP delivery system**. The radishes flourished with this enhancement. We found that while it did not have the highest average height, PAM SAP with fruit peel extract had 12 plants grown total after 2 weeks, which is the largest amount of plants grown. In terms of plant height, the PAM SAP with fruit peel had an average growth of 2.8 cm and the PAM SAP alone had an average height of 3.7 cm. For this project we feel the success of the Mars soil mix with fruit peel PAM SAP at 12 plants after 2 weeks of growth is of utmost importance. This number of plants was 42% more than the Earth control. Our goal is to help enhance the soil to grow the greatest possible number of plants, so this combination is the most useful for the purposes of our experiment, and for a mission to Mars. In the final phase of the experiment, we wanted to see which crop grew the best in the most successful soil of PAM SAP with fruit peel extract. So we planted radishes, arugula, kale, chard, and lettuce in this soil mix. At the end of two weeks, we found that radishes had both the greatest number of plants grown at 8, representing 37.5 % more than the next successful crop, arugula, and also had the highest average plant height at 3 cm. For Future research, we would like to do a longer-term crop study. Radishes were the most successful of the 5 crops planted in Phase III, but this was within the *Plant Mars Challenge* time frame. Therefore, a longer term study is warranted. Additional future questions include the feasibility of getting nutrient-rich compost transported to Mars, or whether condensed nutrients would be a better solution, and if you can create compost out of the food waste produced during space exploration. Advice we would give to future participants is to not get discouraged if you do not see growth right away. It took us two weeks and a change in our methods to see growth, so it is important to remember that successful planting takes research, patience, and time.

References:

Cartier, K. M.S. (2018, January 12). *Tests Indicate Which Edible Plants Could Thrive on Mars*. EOS. Retrieved October 24, 2022, from https://eos.org/articles/tests-indicate-which-edible-plants-could-thrive-on-mars

“Custom 12x30 Greenhouse for Sacred Heart School in Greenwich, CT.” *Custom 12x30 Greenhouse for Sacred Heart School in Greenwich, CT | Baystate Outdoor Personia*, https://outdoorpersonia.com/recent-projects/custom-12x30-greenhouse-for-sacred-heart-school-in-greenwich-ct.

Flurry, A. (2020, October 27). *Geologists dig into question of Martian soil fertility*. UGA Today. Retrieved October 25, 2022, from https://news.uga.edu/geologists-study-martian-soil-fertility/

Kasiviswanathan P, Swanner ED, Halverson LJ, Vijayapalani P (2022) *Farming on Mars: Treatment of basaltic regolith soil and briny water simulants sustains plant growth.* PLoS ONE 17(8): e0272209. https://doi.org/10.1371/journal. Pone.0272209

“Plant Light House® with Light Bulbs.” *Carolina.com*, https://www.carolina.com/wisconsin-fast-plants-supplies/plant-light-house-with-lightbulbs/159004.pr?question=greenhouse. Accessed 19 September 2022.

Romero, J. (2020, October 17). *Turning the Red Planet green: How we'll grow crops on Mars*. Science Focus. Retrieved October 25, 2022, from https://www.sciencefocus.com/space/turning-the-red-planet-green-how-well-grow-crops-on-mars/

Romoser, W. (2019, November 21). *NASA Photos Show Insect- and Reptile-Like Life Forms on Mars, Entomologist Says*. Sci News. Retrieved October 28, 2022, from https://www.sci.news/space/insect-reptile-like-life-forms-mars-07830.html

Wamelink, G., Frissel, J., Krijnen, W. & Verwoert, M. (2019). Crop growth and viability of seeds on Mars and Moon soil simulants. *Open Agriculture*, *4*(1), 509-516. https://doi.org/10.1515/opag-2019-0051

Wamelink GWW, Frissel JY, Krijnen WHJ, Verwoert MR, Goedhart PW (2014) *Can Plants Grow on Mars and the Moon: A Growth Experiment on Mars and Moon Soil Simulants.* PLoS ONE 9(8): e103138. doi:10.1371/journal.pone.0103138