Growing Carrots Beyond Earth: Effects of Simulated Lunar Soil Mixtures on the Germination and Early Growth of Daucus carota

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Abstract

This experiment investigated how varying percentages of simulated lunar soil affect the germination and early growth of carrot plants (Daucus carota). Ten pots were prepared with soil mixtures ranging from 0% to 100% lunar soil, and plant height and leaf development were measured over a fixed growth period. Our results showed that all carrot seeds germinated, even in 100% simulated lunar soil. However, moderate lunar soil mixtures (30%–70%) produced the tallest and most consistent plants, while high lunar soil percentages (80%–100%) showed greater variability in growth. Leaf development corresponded with plant height, indicating active photosynthesis and healthy early growth. The average final height across all treatments was 3.02 cm. Based on these findings, we rejected the null hypothesis and accepted the alternative hypothesis, concluding that lunar soil percentage affects carrot growth. This study demonstrates that carrot plants can grow in lunar soil simulants when combined with Earth soil, providing insights into sustainable food production for future space missions. Additionally, this project encourages STEM learning by promoting hands-on scientific inquiry, collaboration, and problem-solving skills, while inspiring curiosity about space agriculture and extraterrestrial sustainability.

Background Research

Importance of Space Agriculture

- As space exploration advances, growing plants beyond Earth is essential for **sustainable food production** during long-term missions.

Characteristics of Lunar Soil

- The Moon's surface is covered with **regolith**, which lacks **organic matter and essential nutrients** needed for plant growth.

Plant the Moon Challenge Jr.

- NASA's **Plant the Moon Challenge Jr.** encourages students to investigate plant growth in **simulated lunar soil** to prepare for future extraterrestrial agriculture *(Plant the Moon Challenge Jr., 2023)*.

Previous Scientific Research

- Studies show that plants can **germinate and grow in lunar-like soil**, although growth may vary depending on **nutrient availability and soil composition** *(NASA, 2022; Natural History Museum, 2022)*.

Research Goals

- **Investigate how different percentages of simulated lunar soil affect carrot plant growth by measuring final plant height.**
- **Evaluate whether lunar regolith–based soil mixtures can support plant growth.**
- **Contribute to understanding sustainable food production for future space exploration.**

Hypothesis

Null Hypothesis (H_0)

There is no significant effect of increasing simulated lunar soil percentage on the growth of carrot plants. Changing the amount of simulated lunar soil in the planting medium will not affect the final plant height or overall growth of carrot plants.

Alternative Hypothesis (H_1)

Increasing the percentage of simulated lunar soil will affect the growth of carrot plants. Carrot plants grown in different percentages of simulated lunar soil will show differences in final height and growth performance.

Research Question

- How does changing the amount of lunar soil in the soil mix affect carrot seed germination?
- How does the percentage of lunar soil affect the height and early growth of carrot plants?
- Which mix of lunar soil and Earth soil provides the best conditions for healthy leaf development and overall plant growth?

Variables

Independent Variable

- Percentage of simulated lunar soil in the soil mixture (0%–100%)

Dependent Variable

- Final plant height (cm)

Controlled Variables

- Type of plant (carrot, *Daucus carota*)
- Seed type and number
- Amount of water

- Light exposure
- Container size and soil volume
- Planting depth
- Growth duration
- Environmental condition

Methodology

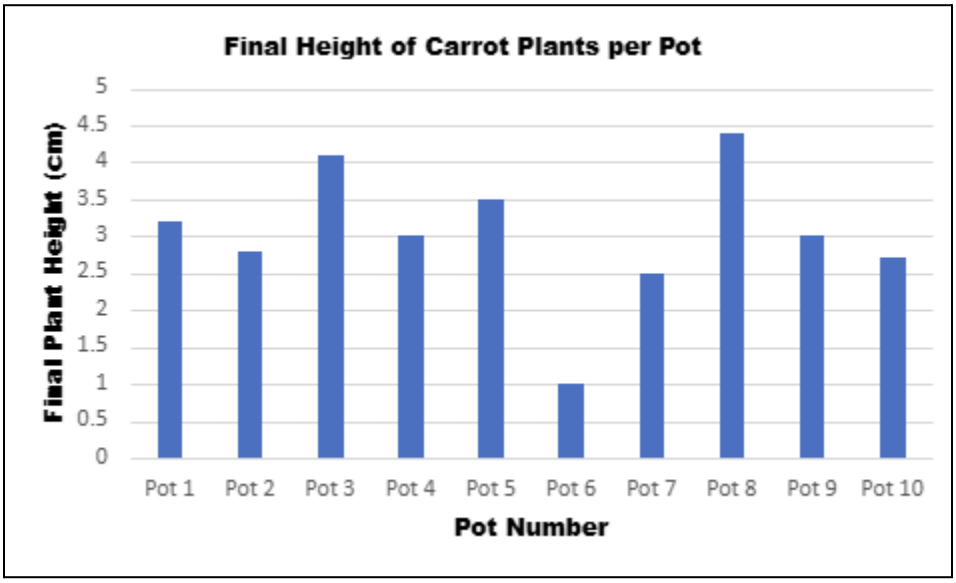
1. Preparation of Pots: Ten identical planting pots were filled with soil mixtures containing different percentages of simulated lunar soil combined with Earth soil (0%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 100%).
2. Labeling: Each pot was clearly labeled according to its lunar soil percentage.
3. Planting Seeds: Carrot seeds were planted at the same depth in each pot.
4. Watering and Light Conditions: All pots received the same amount of water at regular intervals and were exposed to identical light conditions.
5. Monitoring Growth: Plant growth was observed daily, and leaf development and overall plant health were recorded.
6. Measuring Final Plant Height: At the end of the growth period, the final height of each carrot plant was measured in centimeters. These measurements provided the data for Graph 1 (Final Height per Pot).
7. Data Organization and Analysis:
   - 7.1. Heights were averaged to calculate the mean plant height, displayed in Graph 2 (Average Final Height).
   - 7.2. Heights were plotted against lunar soil percentages, resulting in Graph 3 (Plant Height vs. Lunar Soil Percentage).
8. Statistical Summary: Graphs and basic statistics were used to identify trends, variability, and correlations between soil composition and plant growth.

Quantitative Results

Final heights of carrot plants grown in varying percentages of simulated lunar soil ranged from **1.0 cm to 4.4 cm**, with an **average height of 3.02 cm**. Growth occurred in all pots, including those with high percentages of lunar soil, demonstrating that the soil did not prevent germination or early development.

- **Control group (0% lunar soil, Pot 1):** 3.2 cm
- **Moderate lunar soil mixtures (30%–70%, Pots 2, 3, 4, 7, 8):** Heights ranged from 2.8 cm to 4.4 cm, with the tallest plant at **Pot 8 (4.4 cm)**
- **High lunar soil mixtures (80%–100%, Pots 5, 6, 10):** Showed greater variability, including the shortest plant at **Pot 6 (1.0 cm)**

Leaf development corresponded with height. Taller plants produced multiple long and clover-like leaves, indicating active photosynthesis and healthy growth, while shorter plants had smaller or fewer leaves.



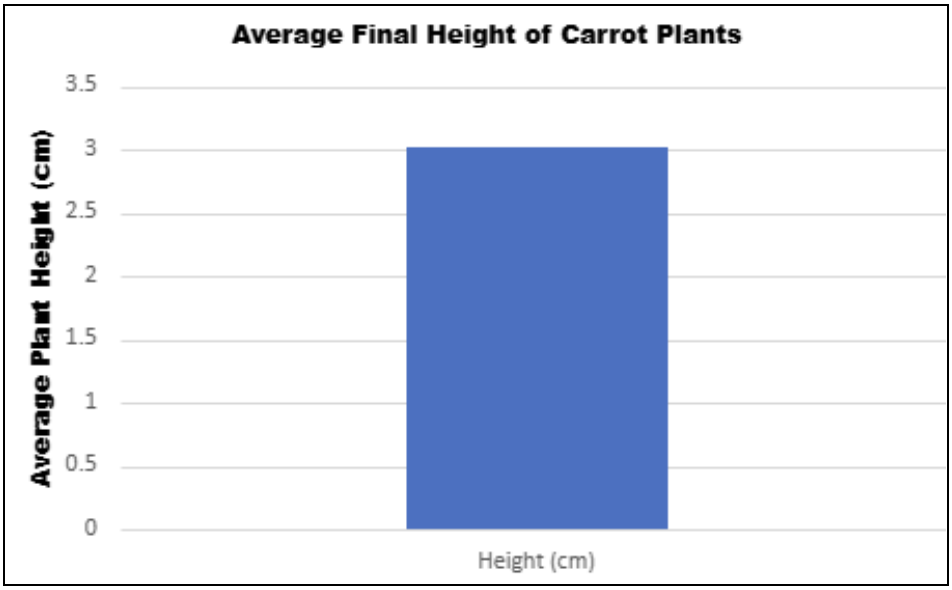
Graph 1: Final Height of Carrot Plants per Pot

This bar graph demonstrates the variation in plant height across individual pots.

- Moderate lunar soil mixtures (30%–70%) consistently produced taller plants (e.g., Pot 3: 4.1 cm; Pot 8: 4.4 cm).
- High lunar soil percentages (80%–100%) showed greater variability and shorter plants (Pot 6: 1.0 cm).

- The control group (0% lunar soil, Pot 1: 3.2 cm) grew well but did not surpass the moderate mixtures.

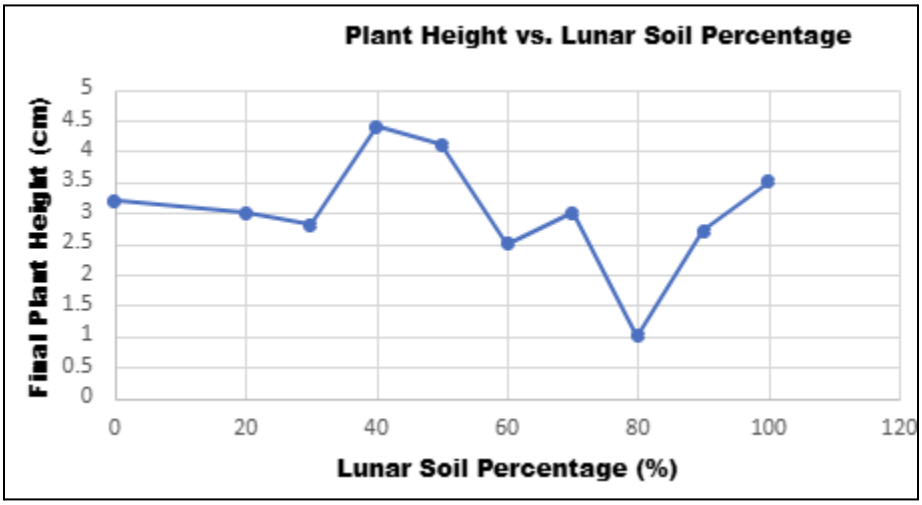
Interpretation: A moderate mixture of lunar soil and Earth soil provides optimal growing conditions, likely due to nutrient balance and improved soil structure.



Graph 2: Average Final Height of Carrot Plants

The overall mean final height was **3.02 cm**, indicating that simulated lunar soil, even in high percentages, does not prevent growth.

Interpretation: Despite variability in individual pots, the average height demonstrates the resilience of carrot plants and the potential feasibility of using lunar soil in extraterrestrial agriculture.



Graph 3: Plant Height vs. Lunar Soil Percentage

The scatter plot shows plant height in relation to lunar soil content:

- Optimal and consistent growth occurred at **moderate lunar soil percentages (30%–70%)**
- Higher lunar soil percentages (80%–100%) supported growth but with increased variability
- Trendline analysis suggests a **non-linear relationship**, where growth peaks at moderate lunar soil content rather than declining linearly with lunar soil percentage

Interpretation: Soil composition affects plant growth. Mixing lunar soil with Earth soil provides the best balance for consistent growth, while 100% lunar soil may limit nutrient availability.

Discussion

The results of our investigation show that carrot plants (Daucus carota) were able to germinate and grow in all soil mixtures, including those containing 100% simulated lunar soil. However, plant growth was not consistent across all treatments. Our data indicate that soil composition influenced early plant height and leaf development.

Moderate lunar soil mixtures (30%–70%) produced the tallest and most consistent plant growth. The tallest plant was recorded in Pot 8 (70% lunar soil) with a final height of 4.4 cm. These mixtures may have provided a better balance of structure and nutrient availability compared to higher lunar soil concentrations. The Earth soil likely contributed organic matter and nutrients, while the lunar soil may have improved drainage and aeration.

In contrast, high lunar soil mixtures (80%–100%) resulted in greater variability in plant height. Although plants still germinated, the shortest plant was observed in Pot 6 (90% lunar soil) at 1.0 cm. This suggests that high simulated lunar soil content may reduce the availability of nutrients needed for consistent early growth. Since lunar regolith simulant contains little to no organic matter, plants grown in higher percentages may have experienced limited nutrient support.

Leaf development followed the same pattern as plant height. Taller plants produced more developed and longer leaves, indicating stronger photosynthetic activity and healthier early growth. Shorter plants generally produced fewer or smaller leaves, suggesting reduced energy production and slower development.

Overall, our results suggest a non-linear relationship between lunar soil percentage and early carrot growth. Rather than plant height decreasing steadily as lunar soil increased, the best growth occurred at moderate levels, and growth became less consistent at very high percentages. Because differences in plant height were observed across treatments, we rejected the null hypothesis and supported the alternative hypothesis.

Conclusion

Based on the results of our experiment, we conclude that the percentage of simulated lunar soil affects the germination and early growth of carrot plants. All pots successfully produced germination, showing that carrot seeds can begin development even in 100% simulated lunar soil. However, plant height and leaf development varied depending on the soil mixture.

The tallest and most consistent growth occurred in moderate lunar soil mixtures (30%–70%), while higher lunar soil percentages (80%–100%) resulted in greater variability and reduced growth in some pots. Therefore, we rejected the null hypothesis because increasing lunar soil percentage did affect early carrot growth. We accepted the alternative hypothesis because different soil mixtures produced measurable differences in plant height and development.

These findings suggest that simulated lunar soil may support early plant growth when combined with Earth soil and that mixed growing media may be more effective than using lunar soil alone for future space agriculture.

Importance of the Study

Our results are important because they show that lunar soil can support early plant growth, helping us understand how plants might grow on the Moon. This study also encourages STEM learning and scientific exploration in our school and community.

Space Agriculture: Our experiment shows that carrot plants can grow in mixtures of lunar and Earth soil. This helps scientists learn how to grow food in space and could be useful for future Moon or Mars missions.

STEM Learning and Science Skills: By working as a group, we practiced observation, measurement, and problem-solving. This hands-on experience teaches important science skills used in middle school, high school, and college-level STEM studies.

Community and Inspiration: Sharing our project can inspire other students and community members to explore science, try experiments, and be curious about space and the natural world.

Sustainability and Innovation: Learning how plants grow in unusual soils can help scientists develop new ways to grow food in extreme environments, both in space and on Earth.

Future Plans

In future studies, we plan to expand and improve this experiment to better understand plant growth in extraterrestrial environments. Our future plans include:

- Testing nutrient supplementation (such as compost, fertilizer, or nutrient solution) in higher-percentage lunar soil mixtures to determine whether nutrient limitations caused reduced growth.

- Increasing the number of trials and adding replicates for each soil percentage to improve reliability and reduce variability.

- Extending the observation period to monitor later stages of growth, including root development, leaf expansion, and overall plant health.

- Measuring additional variables such as germination rate, leaf count, root length, and biomass instead of plant height alone.

- Comparing multiple plant species to determine whether other crops grow more successfully in lunar soil mixtures.

These improvements will strengthen our conclusions and provide deeper insight into sustainable farming strategies for future lunar missions.

References

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