# Exploration of Emergent Technologies In Sustainable Lunar Agricultural Engineering

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## Abstract

Smart agriculture employs advanced technologies to improve the productivity and quality of crops while simultaneously reducing labor with autonomous systems. FarmBot, an open-source robotic farming device, can be programmed to assist with planting, watering, and weeding. This advanced agricultural machinery has applications extending beyond Earth to potential space agricultural settings. Our project involves a focus on utilizing the watering aspect of the FarmBot to sustain our set-up of growing spinach with two lunar regolith simulant soils of varying concentrations. The spinach (*Spinacia oleracea*) plants exhibited the best growth, as indicated by the largest leaf widths, in the 75% regolith simulant concentrations for both types of simulants. This is determined to be due to the appearance of crustose lichen (*Rhizocarpon geographicum*) in these containers. Another avenue of space farming exploration includes aeroponics, a soil-less growing technique where roots are suspended in air and misted with nutrient-rich water. We are using a Tower Garden, a vertical aeroponic growing apparatus, to test the benefits of aeroponics. Both the FarmBot and Tower Garden are vital, accessible tools with the potential to revolutionize the future of farming from Earth to the Moon.

## Introduction

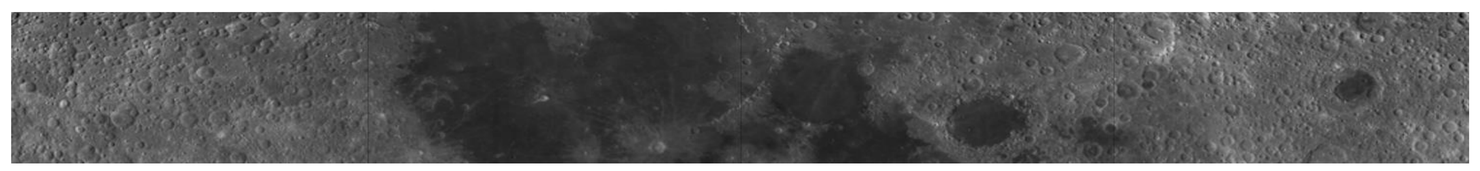

Figure 1: Moon Trek [8] image of the lunar surface, depicting darker mare and lighter highland regolith soils

A steady stream of food production is essential for any lunar habitat. Lunar simulants, replicating the properties of moon soil (Figure 1), are crucial for testing plant growth [4]. This research can help develop agricultural systems for the moon and improve plant productivity in harsh lunar conditions while promoting sustainable practices and optimizing resource usage. Technologies can facilitate sustainable agricultural practices to reduce labor and optimize resource usage. At the University of Maryland, Eastern Shore, we are using lunar highland simulant (LHS-1) from the University of Central Florida's Exolith Lab and lunar mare simulant (MLM-1) from New Mexico State University (Figure 2). Our indoor experiments use a FarmBot Express, an open-source robotic farming device, for autonomous watering (Figure 3). We will assess the FarmBot's effectiveness and study spinach growth under different regolith simulant conditions. Additionally, we are exploring aeroponics [5] with the Tower Garden FLEX, a vertical, aeroponic growing system, for simple and sustainable plant cultivation (Figure 4).

Figure 2: MLM-1 mare (top) and LHS-1 highland (bottom)

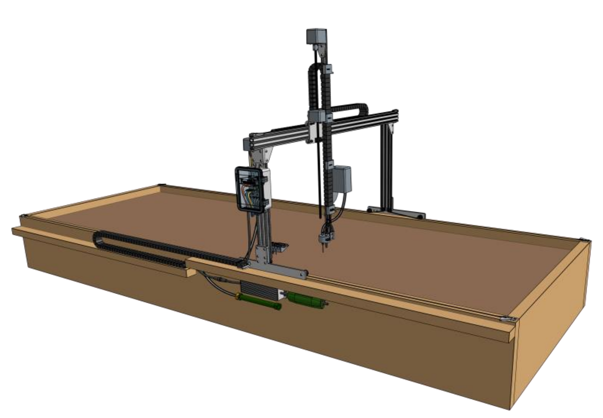

Figure 3: FarmBot Express 3D CAD model

Figure 4: Tower Garden Express model

## Research/Educational Objectives

- To implement sustainable platforms for growing edible plants, with potential applications in space.
- To examine the advantages and limitations of agricultural technology to ensure reliability and efficiency in lunar environments.
- To integrate multidisciplinary knowledge through understanding and addressing the complexities of lunar agriculture by combining insights from various scientific disciplines and engineering.

## Materials and Methods

Spinach (*Spinacia oleracea*) planted in mixtures of two types of regolith simulants in five containers [i.e., five mares (MLM-1) and highlands (LSH-1)] with 2500 grams in each (Figure 12).

- Conditions: 100% potting soil, 25% regolith and 75% potting soil, 50% regolith and 50% potting soil, 75% regolith and 25% potting soil, and 100% regolith
- One replicate for each condition, with exception of a control (100% potting soil) for MLM-1.
- Horse manure added as fertilizer per 1% of regolith.
- FarmBot Express [1] for autonomous watering with Lua sequencing on alternate days for 3 seconds (Figures 7-9).
- Grow lights set on a timer for a 12-hour duration (i.e., 6 am to 6 pm).

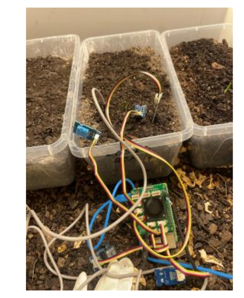

Figure 11: FarmBeats sensors in action

Figure 10: FarmBot watering plants

Similar process on a smaller scale, with kale (*Brassica oleracea*), in an independent laboratory using grow lights without a FarmBot (Figure 6). Environmental conditions (temperature, humidity, light intensity) monitored weekly with FarmBeats [3] sensor kit (Figure 11) and Data Streamer in Excel. Observations and growth parameters (e.g., height and width) documented.

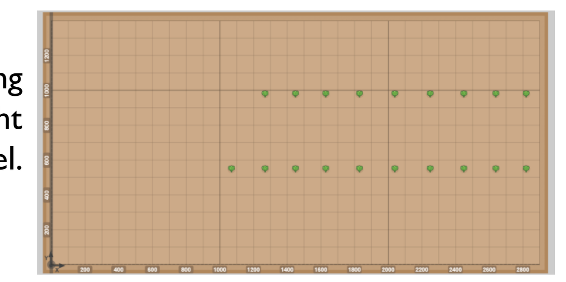

Figure 9: Spinach placement modeled in FarmBot Web App

Figure 5: Tower Garden FLEX with Bibb and Gourmet Lettuce

Two Tower Garden FLEX products [2] assembled according to the packaging instructions (Figure 5).

- Seeds planted in rockwool cubes and covered with vermiculite in germination tray for two weeks.
- Reservoir filled with water mixed with nutrient solution.
- Seedling transplanted into the net pots after growing.
- Without Extension: 9 Bibb Lettuce (6 treatments, 3 controls) and 11 Gourmet Lettuce (6 treatments, 5 controls)
- With Extension: 10 Basil (7 treatment, 3 controls), 10 Arugula (7 treatments, 3 controls), and 8 Rainbow Chard (5 treatments, 3 controls)
- Liquid seaweed growth stimulant sprayed on designated plants every Wednesday.

Figure 7: Indoor FarmBot Express in large scale regolith simulant set-up

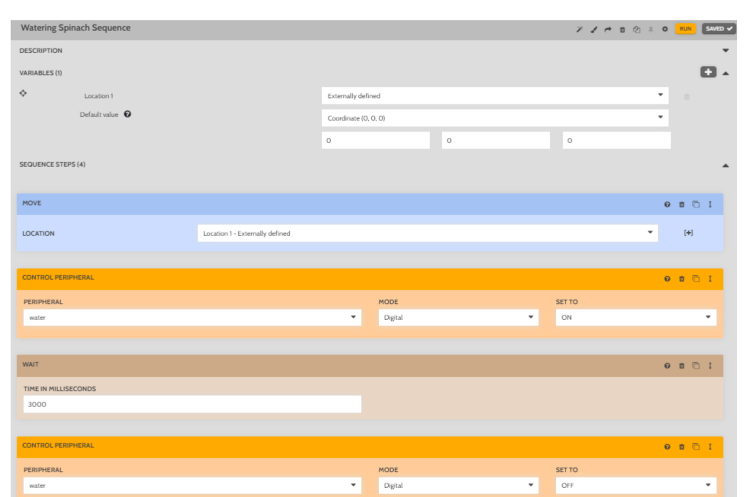

Figure 8: Lua sequencing for FarmBot watering

Figure 12: Top view of regolith set-up with the spinach and rocks

## Results and Discussion

FarmBot Express

- Precise positioning and open-source nature allows for vast customization to needs.
- Water pressure causing cratering, disrupting the soil structure and plant growth due to uneven water distribution ⇒ placed rocks in water stream (Figure 10).
- Connection and calibration issues time-consuming for users to troubleshoot.
- Lower carbon footprint as vegetables emit 25-30% less $CO_2$ than store-bought.

Regolith Simulant Experiment

- 50% mixtures for both types germinated earliest and 100% mixtures a week later.
- LHS-1 had a higher sprout rate compared to MLM-1 (i.e., 90% vs. 72%).
- Best growth (i.e., leaf widths) in 75% mixtures for both types (Figure 13 and 14) ⇒ presence of crustose lichen (*Rhizocarpon geographicum*) (Figure 16) improves water retention and provides nutrients (nitrogen, phosphorus, and potassium).
- Limited growth ⇒ heat exceeding best temperatures for spinach and spinach performed worst on regolith simulants in studies [6].
- Spinach in LHS-1 75% regolith was consistently the largest until LHS-1 100% regolith, at the end, surpassed.

Tower Garden FLEX

- Accessible for those with limited space or mobility to grow healthy produce (Figure 15).
- Uses 2% of water from traditional gardening and vertical design uses 90% less space.

Figure 15: Lettuce in Tower Garden after a month

## Results and Discussion Cont.

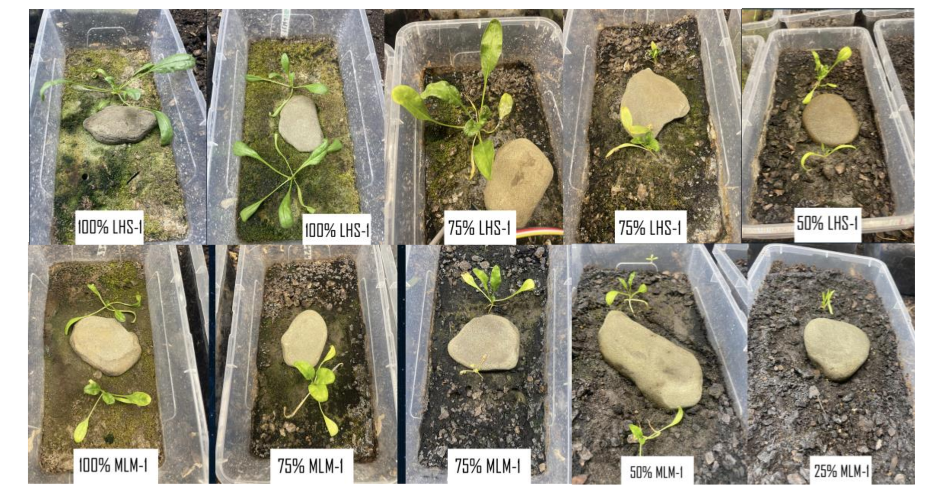

Figure 14: LHS-1 and MLM-1 spinach growth of various mixtures

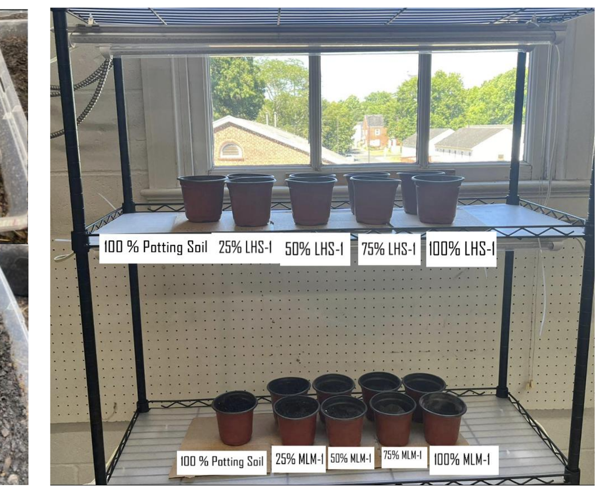

Figure 6: Small-scale regolith set-up with kale

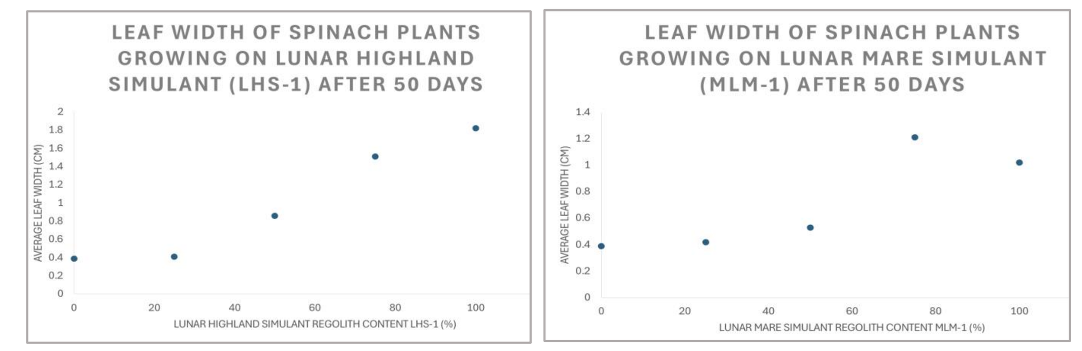


Figure 13: Spinach leaf width data for varying concentrations of MLM-1 and LHS-1 after 50 days

Figure 16: Close-up of the lichen

## Conclusions

Technological applications are vital for enhancing productivity, sustainability, and accessibility in both terrestrial and lunar agriculture, supporting long-term human presence. Various technologies and agricultural practices, such as autonomous farming robots (FarmBot Express) and aeroponics (Tower Garden FLEX), have their advantages and limitations. Future developments should focus on improving FarmBot's scalability and integrating vertical aeroponic systems to combine the strengths of both designs for agricultural automation. Further research will explore other plant types and the use of lichen as a fertilizer on regolith.

Current investigations include using an Arduino clinostat to simulate lunar microgravity for growing cress, examining plant responses to gravity when this stimulus is removed.

This project addresses three grand challenges in engineering [7]:

- Managing the nitrogen cycle by optimizing plant growth in various soil compositions.
- Engineering tools of scientific discovery by devising systems to study plant growth in simulated harsh lunar environments.
- Developing carbon sequestration methods through efficient, space-saving agricultural devices.

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