Evaluation of Lunar Regolith Enrichment Techniques for its Usage as Substrate on *in situ* Crop Production

Authors: Yael N. Méndez[1], Oscar I. Ojeda[2] , Javier E. Suárez [3], Julián A. Corzo[4]
1 M.Sc. in Geology student,Universidad Nacional de Colombia 2 M.Sc Aerospace Engineer student, Purdue University, 3 Associate professor and M.Sc. In geology, Universidad Nacional de Colombia, 4 (c) PhD in Geology, Universidad Nacional de Colombia

Abstract
Future long duration missions and lunar settlements will have to rely on *in situ* production of food to make missions viable. This feat requires early exploration missions to characterize what type of local resources can be used and what processing they require in order to be a viable means for crop production. By analyzing different regolith compositions, subject to potential enhancers for soil microbiome, this proposal aims to identify the best strategy for aiding in crop production on planetary surfaces, starting on the Moon. In addition, human waste is proposed as a source for regolith enrichment, as another in situ resource.

Introduction
Future human space exploration poses challenges to the sustainability of human life. There are two methods to meet the goals of life support: replenishment and regeneration of materials. Replenishment implies very high costs for the mission, while the regeneration of materials not only allows to lower operating costs but also to reuse available *in situ* resources and use waste as energy sources and nutritional supplements (Seligman, 2017)

Closed cycle life support systems are key for long duration space missions, and one of the primary needs of crewed space travel is to resolve the issue of food (Häder et al., 2018). Taking into account that in a long-term space mission it is not optimal to carry enough food to supply the entire duration of a mission, it is necessary to study the possibility of generating the food in space (Kanazawa et al, 2001). One alternative is based on adaptive processes of plants subjected to different growth conditions and enriched local substrates that allow the development of efficient crops (Levrino et al., 2014)

Another technological challenge that arises from this mission is the management of human waste that must be disposed of correctly to avoid contamination by following planetary protection protocols. Human beings generate organic waste that could potentially be reused to produce composting (Levrino et al., 2014; Salisbury, 1991; Sauer & Jorgensen, n.d.). For the Apollo missions, a waste management system was designed where liquid waste such as urine, solid fecal matter and stowage gases from the astronauts were collected, calculating their weight and volume. These materials are stored in a container (Sauer & Jorgensen, n.d.)
This composting may play a role in the production of efficient crops that meet the nutritional needs of the crew of future long duration missions or lunar settlements. Lunar regolith will be the main lithologic unit in contact with human activity, the principal elements available in lunar soils are Si, Fe, Ti and Mg (Taylor et al., 2016) and it is almost depleted of N, P, K and C. All of them are key in biologic activities, so the recycle and composting of organic wastes to supplement lunar regolith as a mean for crops may be a valuable process in life-support systems.

Methodology
In the Artemis III mission architecture, two astronauts will stay on the lunar surface for 6.5 days performing different EVAs. This proposal takes this into account, and consists of a methodological approach of 3 steps:

1. Astronauts will collect regolith samples of different characteristics in terms of composition and then will proceed to sift them by granulometry. The collected samples will be characterized and separated in batches.
2. The batches will be treated by an experimental methodology to be specified in terms of repetitions, and will broadly consist of the

treatment of the regolith samples with a combination of hyper-thermophilic aerobic composting bacteria (Symbiobacterium thermophilum and thermo- philic Bacillus strain S) (Kanazawa et al.,2008) or plant growth-promoting microorganism as inoculants in agricultural soils, they provide essential plant nutrients supplement such as nitrogen, phosphorus and potassium (de Souza et al., 2015), organic nutrient supplement simulator and/or human waste simulant.

3. The samples will undergo a first characterization that quantifies the viability of the treated soil as a base for crop growth by means of turbidity techniques. We propose possible treatments as follows:
   Treatment A: Lunar regolith + UV radiation.
   Treatment B: Lunar regolith + simulated organic nutritional supplement + UV radiation.
   Treatment C: Lunar regolith + waste simulant + UV radiation.
   Treatment D: Lunar regolith + Plant growth-promoting microorganism/ hyperthermophilic bacteria+ waste simulant + simulated organic nutritional supplement + UV radiation.
4. The samples will be sealed and returned to Earth for further analysis. Planetary protection protocols must be taken into account.

Projected results

1. Identify the best technique for regoliths enrichment for future efficient crop production.
2. Study the metabolic interaction between growth-promoting microorganism and lunar regolith.
3. Identify challenges for using lunar soil as a substrate in producing efficient crops for a lunar base.

Challenges

The characterization may yield as a result that the viability of regolith enrichment is low, and that techniques such as hydroponics or aeroponics result favored for crop production in future space missions. Also, some residual components of human waste may turn out to be harmful for the wellbeing of the crew, resulting in an impossibility to use it, in particular for food production plants. Because of its original conditions, regolith batches may require additional treatments before it is used in the enrichment process.

References

Häder, D. P., Braun, M., & Hemmersbach, R. (2018). Bioregenerative life support systems in space research. In Gravitational Biology I (pp. 113-122). Springer, Cham.

de Souza, R., Ambrosini, A., & Passaglia, L. M. P. (2015). Plant growth-promoting bacteria as inoculants in agricultural soils. Genetics and Molecular Biology, 38(4), 401–419. https://doi.org/10.1590/S1415-475738420150053

Kanazawa, S., Ishikawa, Y., Tomita-Yokotani, K., Hashimoto, H., Kitaya, Y., Yamashita, M., Nagatomo, M., Oshima, T., & Wada, H. (2008). Space agriculture for habitation on Mars with hyper-thermophilic aerobic composting bacteria. Advances in Space Research, 41(5), 696–700. https://doi.org/10.1016/j.asr.2007.09.040

Levrino, L., Gatto, G., Hall, S., Wellons, J., Gargioli, E., Hoffman, J. A., Maggiore, P., Viola, N., & Viscio, M. A. (2014). Human life support in permanent lunar base architectures. Proceedings of the International Astronautical Congress, IAC, 13(October), 9690–9700. https://doi.org/10.13140/2.1.3002.2406

Salisbury, F. B. (1991). Biogenerative life-support system: Farming on the Moon. Acta Astronautica, 23(C), 263–270. https://doi.org/10.1016/0094-5765(91)90126-P

Sauer, R., & Jorgensen, G. (n.d.). Waste management system. SP-368 Biomedical Result of Apollo. Retrieved September 8, 2020, from https://history.nasa.gov/SP-368/s6ch2.htm

Seligman, L. (2017). Life support. Aviation Week and Space Technology, 179(22), 62–63.