CALIBRATING PLANT WATERING SYSTEM MODELS WITH LONGTERM LUNAR CAPILLARY DATA.

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Introduction: The first crewed lunar missions offer unique opportunities for developing enabling technologies to support future manned exploration missions in lunar and Martian surface habitats. Crop production systems reduce risks to the crew that result from inadequate diets by providing fresh crops during long duration missions [1]. Traditional agricultural systems on Earth utilize soils for supporting the plants and for providing nutrients required for crop growth. Soil-based systems have been adapted for use in microgravity on ISS, however, these systems are not sustainable for future plant growth systems during long duration exploration missions [2]. Soil-based systems are heavy, bulky, and require large volumes of resupply because only a few crops can be grown in a given soil volume. Thus, soil-less plant substrates (ie. using capillary foams) or hydroponic systems (e.g. nutrient film technique) must be adopted for sustainable crop production subsystems [3].

The design of future water systems using capillary systems critically depends on current porous-media hydraulic models for use in partial gravity which have only been tested using short term data sets obtained during parabolic flights [4-6] and some limited microgravity experiments aboard the ISS [7,8]. These experiments have suggested a reduction in the initial wetting advance (imbibition [9]) into dry substrates, and an increased importance of process-dependent wetting and drying (hysteresis) [10,11] on the fluid distribution in partially wet substrates. Hysteresis is currently not considered as a design variable for irrigation and is suspected to be the reason for overwatering observed in microgravity compared to terrestrial set points [12-14].

The characteristic time and length scales for imbibition into dry media and observation of hysteresis at plant relevant partial saturations require experiment durations well in excess of 20s [15]. These data are needed for improving models used for management of water and gas exchange in substrates [16,17]. They are also ultimately needed as design characteristics for porous substrates, such as foams, which not only offer a weight advantage over granular media, but also a larger degree of manipulation of pore sizes, shapes and arrangements specifically targeted for lunar gravity conditions [18-20].

We propose to conduct a simple, long-term water imbibition and fluid redistribution experiment either in a manned habitat, or in a cargo ship, on the surface of the Moon. The goal is to collect the behavior of fluid movement through 6 capillary substrates (three granular calcined clays and three polymeric foams with different pore size distributions).

Methods: The proposed demonstration will consist of deploying a payload containing six capillary substrates to either a crewed lunar habitat or a cargo ship on the Moon. The system will consist of an automated watering system, a small LED light bank, a self-contained root module (including a prefilled water reservoir and automated watering system), a sensor suite (embedded moisture, tension and oxygen sensors), and an imaging system to record water imbibition experiments. The system will be designed to conduct pre-programmed water imbibition studies. The self-contained root module houses a controller to power the light bank, operate the watering system, and collect time course images and sensor readings during the experiment. Data collection and teleoperation would be accomplished via telemetry and ground commanding capabilities. Once the experiment reaches the lunar surface, it will require: 1) experiment initiation, 2) imbibition and image acquisition, and 3) transfer of image and sensor telemetry. In a manned habitat, the crew would connect the payload to telemetry and power bus of the habitat. The experiment would be completed in seven days and require minimal crew involvement, as no sample return is required. Since crew time is not required to meet science goals, the experiment could be conducted if the payload is deployed in a cargo ship to the lunar surface.

Dimensions. The footprint of the root module containing the capillary substrates ranges from 0.1-0.2 m^2. The root module will rely on the air revitalization subsystem of the lunar habitat for supplying O_2 to the substrates, as well as temperature and humidity control.

Self-Contained Root Module The root module will consist of a watering system composed of 6 cells, each instrumented with moisture, tension and O_2 sensors embedded in the capillary substrates. The watering system will consist of a water reservoir, a manifold, and a peristaltic pump. The root module will house a controller responsible for telemetry, for recording environmental sensors (O_2 concentration, light level, moisture, temperature, and humidity), for operating the watering system, for controlling the LED light bank, and for operating the imaging system. The root module would require 50 W for operation. A white LED light bank requiring 30 W provides illumination required for the imaging system. The LED light bank will be controlled by a controller housed in the root module.

Imaging System. The imaging system and the sensor suite will collect all the data. Thus, the experiment does not require sample return to meet the science objectives. A single commercial camera will collect images of imbibition in each capillary cell and will be assessed on Earth.

Imaging will be relayed back to Earth for analysis via the payload telemetry system. Near-real time changes in watering setpoints or lighting would be made to accommodate changes mission scenario via teleoperation from the ground. The imaging and environmental data collected will be sufficient for achieving the scientific goals of the mission and for conducting a suitable ground control.

System Technology Readiness Level (TRL): The TRL of the individual components (imaging, watering, and control systems) is currently 6-7. Their individual TRL, as well as the TRL of the integrated system, will have been demonstrated on Earth (TRL 9) prior to this proposed demonstration on the lunar surface.

Return cargo requirements: None.
Mission Duration: 7 days.

Science Goals: With a shift to more capillary dominated fluid distributions and flow in reduced gravity comes the need to manipulate macroscopic fluid distributions and interfacial surfaces in novel ways to achieve sustainable crop production with a minimum of substrate. Designing these media can only be achieved if we understand altered distributions of fluids in porous media with varying degrees of hysteresis and wettability.

The goal is to test macroscopic spatial fluid distributions and develop novel modeling capabilities to predict connectivity of fluid-filled pathways and interfacial area in substrates. The data are needed to not only choose a correct pore-size distribution to meet connectivity requirements, but to manipulate the spatial arrangement of pore-sizes. This experiment will be the first time that longterm imbibition data through capillary substrates is collected under the influence of partial gravity.

The proposed system requires minimal crew intervention (initial unstowing and disposal of the root module) if deployed on a manned lunar habitat. Alternatively, the system could be deployed in a cargo vehicle as long as a suitable supply of air is present.

Environmental data collected during the mission will be used for conducting a ground control. The performance of the capillary experiment system will be compared to an identical experiment performed on Earth.

Conclusions: Understanding the influences of partial lunar gravity are critical for designing future sustainable surface plant growth systems to be used for producing fresh crops for crew consumption. The physical characteristics of the substrate are crucial design characteristics because they determine the physical aspects of root function such as water, nutrient and gas exchange that are most relevant to root growth and plant vigor. We propose to collect imbibition and moisture hysteresis data to test hydraulic models of capillary flow and distribution. These models are needed to meet resource constraints for designed root zones including water quantity, size, mass and re-useability.

Optimized rootzones for crop production in partial gravity are ultimately needed to support human colonies in space because long term storage reduces the nutrient stability of stored food systems, which poses a major risk of reduced performance and illness to the crew during long duration exploration missions. Thus designing sustainable crop food production systems using optimized soil-less media on the Moon will ensure future sustainability for crop production on Mars.

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References: [1] Anderson, M.S. et al. (2017). *AIAA Sp. Astronaut. Forum Expo. 2017*. [2] Cooper, M. et al. (2017). *npj Microgravity*, 3. [3] Monje, O. et al. (2019). *ICES*-2019-260. [4] Heinse, R. et al. (2007). *VZJ*, 6, 713–724. [5] Langbein, D. et al. (1990). *Appl. Microgravity Tech*. II, 4, 198–211. [6] Nagura, R. et al. (2019). *Adv. Sp. Res*., 63, 589–597. [7] Heinse, R. et al. (2015) *VZJ*, 14. [8] Jones, S.B. et al. 2002. [9] Tuller M. et al. (2009) *Soil Sci Soc Am J*, 73, 341–350. [10] Heinse, R. et al. (2009) *SAE* 2009-01-2360. [11] Heinse, R. et al. (2005) *SAE* [12] Liao, J. et al. (2004) *Adv. Sp. Res.*, 34, 1579–1584. [13] Monje, O. et al. (2003) *Adv. Sp. Res*., 31, 151–167. [14] Chau, J.F. et al. (2005). *Water Resour. Res*., 41, W08410. [15] Heinse, R. et al. (2005) *SAE* 2005-01-2950. [16] Or, D. et al. (2009) *Adv. in Water Res*. [17] Jones, S.B. et al. (1999) Water Res. Res., 35, 929–942. [18] Jones, S.B. et al (2009) *SAE* 2009-01-2361. [19] Jones, S.B. et al. (2005) *SAE* [20] Butz, I. et al. (2019). *Transp. Porous Media*, 130, 463–485.