Literature Review on Lunar Plant Cultivation: Seed Storage, Plant Maintenance, Electromagnetic Protection Dome Construction

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ABSTRACT

During the early days of the space age (Apollo era), the visionary plan was to bring samples of the lunar regolith back to Earth, but thoroughly studying them with advanced equipment and saving them for future research was not yet imagined. It was important to store seeds in a secure airtight packet because they help reduce humidity, which is key to storing seeds effectively. Issues such as climate change, global warming, and food insecurity worsen every year, so in this study lunar plant cultivation has been considered to mitigate these issues.

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1. Introduction

People, including scientists, have long regarded lunar plant cultivation as mere science fiction and far-reaching into the future. However, as issues such as climate change, global warming, and food insecurity worsen every year, lunar plant cultivation has become a reality and a potential solution considered by many to mitigate these issues. Lunar plant cultivation, the growth and production of crops on the Moon's surface, is a nascent topic that many scientists have begun to research on.

During the early days of the space age (Apollo era), the visionary plan was to bring samples of the lunar regolith back to Earth, but thoroughly studying them with advanced equipment and saving them for future research was not yet imagined. Fifty years later in the Artemis era, three of the regolith samples have been used to successfully grow plants. NASA Administrator Bill Nelson states that "this research is critical to NASA's long-term human exploration goals as we'll need to use resources found on the Moon and Mars to develop food sources for future astronauts living and operating in deep space. This fundamental plant growth research is also a key example of how NASA is working to unlock agricultural innovations that could help us understand how plants might overcome stressful conditions in food-scarce areas here on Earth" [1].

According to previous research, lunar soil is cultivable but not as robust as growth from Earth soil. Several aerospace agencies such as the Japan Aerospace Exploration Agency (JAXA), China's Lunar Exploration Program (CLEP), and the National Aeronautics and Space.

Administration (NASA) have experimented with both simulated lunar regolith and lunar regolith. In January of 2019, China's Chang'e 4 spacecraft landed on the far side of the Moon, carrying with it a biosphere that contained five sets of plants and some insects in order to test sustainability of long-term settlements in space. Although the cotton plant successfully sproutedon the Moon's surface, it shortly died after, unable to withstand the Moon's extreme environmental conditions [2]. Additionally, in May of 2022, NASA planted seeds of the flowering weed called Arabidopsis thaliana in lunar soil samples of which were retrieved back in 1969 and 1972. These seeds successfully sprouted, but what was interesting was that the plants reacted differently depending on which soil sample the growth was supported by. In other words, the location where soil samples were collected mattered [3].

In order to construct a sustainable and efficient lunar planting system, this paper divides the process into three different sections: the seed storage process, necessary maintenance (temperature, water, light, fertilizer), and the construction of an electromagnetic protection dome.

2. Seed Storage Process

It is important to store seeds in a secure airtight packet because they help reduce humidity, which is key to storing seeds effectively. Reducing humidity will also reduce the risk of mold and premature sprouting in seeds. Not only do seeds need to be stored in an airtight packet, but they also need to be frozen. Freezing seeds not only helps with seed germination but also helps with long term seed storage, which is particularly handy for space travelers. Seeds will usually be placed near the back of the fridge/freezer to avoid temperature fluctuations from opening and closing its doors. Since 2020, astronauts have used two food fridges called the Freezer Refrigerator Incubator Device for Galley and Experimentation (FRIDGE) on the ISS [4]. The ideal freezing temperature for seed storage is 0 to 10 degrees C. It is very important to set a consistent range of cool temperatures during seed storage. Every 5-6 degree C change in temperature could cost seeds half their storage life.

3. Plant Maintenance

3.1. Temperature

Problems in plant growth most often occur when plants are grown in extreme temperatures that are not ideal for plants. This will most likely be the case on the Moon, for temperature fluctuates between -183 degrees C and 106 degrees C on the Moon [5]. So, what could be solutions to this temperature problem? Firstly, replanting the roots somewhere else on the Moon will not solve this problem because the plants will still experience extreme temperature fluctuations.

Additionally, harvest will also be an infeasible solution, for the plants will not be ready because they have stopped growing prematurely. Thirdly, transporting the plants back to Earth could be a possible solution but could aggravate their growth due to sudden changes in the environment.

Therefore, if current technology and mechanisms allow, adjusting the temperature of the surrounding environment in a separately constructed dome will be the ideal solution. Currently, scientists have used the Active Thermal Control System (ATCS), using a mechanically pumped fluid in closed-loop circuits to perform three functions: heat collection, transportation, and rejection. The remaining waste heat is subsequently eliminated using cold plates and heat exchangers, both of which are cooled by circulating ammonia loops on the station's exterior [6].

While most plants grow best in temperatures ranging from 15 to 30 degrees C, some plants such as wheat thrive in a hot and humid climate. For example, wheat plants thrive in an environment with the average temperature ranging from 21 to 37 degrees C. These plants can tolerate temperatures up to 42 degrees C. To grow wheat on the Moon, optimal temperature must be adjusted accordingly.

3.2. Water

The most common explanation for the wilting of plant leaves is lack of water. While plants need at least 2 inches (5 cm) of water a week, the lack of liquid water found on the Moon poses a foreseeable problem of underwatering for plants. Thus, astronauts must find alternative ways to water their plants on the Moon.

Instead of water, ice (could be used after harvest) is present on the moon and has been found in dark, cold areas such as deep craters or near the Moon's poles. However, the ice on the moon is demineralized, so the minerals and nutrients (nitrogen, phosphorus, potassium) that compost from human feces are very valuable. Additionally, recent technology shows evidence of water molecules on the Moon, especially near some of the moon's large craters such as the Clavius crater in the moon's southern hemisphere. To detect water molecules, NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA) used a special infrared camera that could distinguish between water's specific wavelength of 6.1 microns and the wavelength of hydroxyl, or OH. "Data from this location reveal water in concentrations of 100 to 412 parts per million — roughly equivalent to a 12-ounce bottle of water — trapped in a cubic meter of soil spread across the lunar surface," NASA says [7]. However, these are not puddles of water; but instead, they are water molecules that are so spread apart. Scientists continue to research ways to use these water molecules for plant watering.

NASA offers two possible explanations for the peculiar appearance of water in these regions. First, micrometeorites, carrying small amounts of water, could be raining down on the lunar surface. When micrometeorites collide with the moon, water may be left behind on the surface. Secondly, there could be a two-step process by which the solar wind from the Sun transports hydrogen to the lunar surface and reacts with oxygen-bearing minerals in the soil to produce hydroxyl. It is possible that the radiation from the impact of micrometeorites is turning that hydroxyl into water.

Another important question is how the water is stored and accumulated. The high heat produced by micrometeorite strikes may cause small structures in the soil that resemble tiny beads to develop, trapping the water. Another possibility is that the water may be shielded from sunlight and concealed between grains of lunar soil, making it slightly more accessible than water trapped in bead-like structures [8].

Although ice is a potential source of water that could be used after it is liquefied, a pragmatic question that emerges is: how will humans access these water ice resources buried so deeply in dark craters where temperatures are as low as 400 K? NASA's Jet Propulsion Lab proposes reflecting solar energy using giant mirror reflectors (transported from Earth) into the dark craters, allowing for robotic mining vehicles to dig into the deep craters to extract the hidden water ice.

These mirrors, which will supply energy to overcome ice's high heat capacity, will help sublimate and liquify the solid water ice for plant watering [9].

Another key question then emerges: how will the methods for plant watering be altered to address the different gravitational conditions on Mars? Astronauts actually use a special syringe to inject water directly into "plant pillows," which are special bags that contain the seed. A major concern for many astronauts today is finding a balance between aeration (getting the right amount of air to a plant) and hydration (getting sufficient amount of water to a plant). NASA astronauts discovered that imbalanced air flow could result in high levels of humidity, resembling tropical rainforest conditions that would put plants under a lot of stress. High humidity levels could cause guttation, which is when a plant's internal pressure builds up, forcing excess water out of the leaves. Overhydration also resulted in some plants growing mold or bacteria. Through research projects such as the Plant Water Management (PWM) project, astronauts continue to investigate the best way to water plants in space that address both aeration and hydration [10].

3.3. Light

Although most plants can grow in the shade without light, they need to get enough light to grow large heads and healthy leaves. Moreover, plant growth is slower without light compared to with light (full or partial sun conditions). It is recommended that plants are grown in sunny spots that receive at least 6 hours of sun daily. Similar to Earth, the Moon spins on its axis and goes through daytime and dark cycles. However, the cycles on the Moon are longer than on Earth, as the mean solar day on the Moon is 29.5306 Earth days (meaning 14-15 days of daytime and night time each) [11]. Plants cannot survive 14-15 days without light, so an external light source (other than natural sunlight) must supply light to the plants during the Moon's dark period.

Funding various agricultural programs in the late 20th century, NASA researchers discovered that a certain blend of LED lights could replace hot and heavy incandescent grow lights. Today, installing smart LED lights with precise controls that will not overheat plants is a wise choice.

A combination of red and blue lights generates more light than green LEDs by design, because plants could photosynthesize using red LEDs and avoid becoming too tall and spindly using blue LEDs. Many of today's indoor farms offer plants a similar diet of red and blue photons, appearing bathed in purple light. Similarly, NASA's Expedition 44 crew members have attempted to grow plants under the purple pinkish hue created by the red and blue lights and have successfully grown plants under the Veggie plant growth system [12].

3.4. Fertilizer

Many plants are also heavy feeders of nutrients, quickly depleting the nutrient-rich soil, and thus requiring a constant, steady supply of water and nutrients throughout its growth. If plants become nutrient deficient, they may show symptoms such as yellow discoloration and deformation of leaves.

Worms are essential for the health of the soil and plants, for they feed on organic waste such as the non-eaten remains of the crops. Their excrements are further decomposed by bacteria, releasing important nutrients such as nitrogen and phosphorus into the soil. Worms also enhance soil structure and decrease the density of the hydrophobic lunar soil by excavating burrows, making it easier for water to penetrate the soil. Thousands of worms have already been launched into space for different experiments. Second, bacteria such as Rhizobium binds nitrogen from the air turning it into nitrate and improves soil quality. In fact, Wieger Wamelink, a Mars and Moon soil research expert at Netherlands' Wageningen University, has already tested earthworms and nitrogen fixing bacteria in space-like environments and discovered that they had thrived in the given environments [13]. Potato peels and coffee grounds, both examples of organic matter rich with nutrients inside, improve soil quality by improving water drainage, retention, and aeration in the soil. Coffee grounds can be transported from Earth, and potato peels can be extracted from leftover peels after harvesting them on the Moon. Peat moss and vermiculite are other additives that improve soil health [14]. These additives, which ensure healthy plant growth and a self-sustaining ecosystem, are applicable to various plants such as cabbage plants, radish plants, wheat, tomato plants, and potatoes.

Plants need to grow in fertile, well-drained, and healthy soil. Hard or compacted soil, a defining characteristic of lunar soil, may lead to misshapen tubers and unhealthy lateral stems and buds in potato plants. Lunar soil is also extremely poor in carbon, nitrogen (specifically, NO3 and Nh4), and phosphorus, which are necessary nutrients for almost all plant growth.

Although data from several Earth-lunar regolith experiments (such as the Plant the Moon Challenge) show that combining Earth and Moon soil will provide missing nutrients for plants, it is unrealistic to bring Earth soil to the Moon because of monetary reasons and transportation difficulties. Meanwhile, the recycling of human urine and poop as manure is essential for self-sustaining space agriculture, for resources are heavily limited, and everything humans use and produce must be recycled for efficiency reasons. The nutrient solution in human feces and urine are as follows: ammonium ion (NH_4), Nitrate (NO3). Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), and Sulfate (SO_4). Sawdust may also help materials in the feces decompose and break down into less complicated components, resulting in simpler, nutrient-rich compost [15].

Different plants prefer different amounts of fertilizer for efficient growth. For example, while many plants thrive on nitrogen-rich fertilizer such as sterilized human feces or urine compost, some plants such as the radish plant do not prefer fresh manure or fertilizers high in nitrogen.

Radish plants are sensitive to excess nitrogen in soil, and it may slow the growth of the plants, resulting in small, unhealthy root bulbs with heavy top growth. In these cases, applying phosphorus-rich organic compost such as worm castings or rock phosphates to the soil will encourage plant growth.

4. Construction of Dome

The average temperature on the Moon ranges from -298 degrees Fahrenheit (-183 degrees Celsius) at night to 224 degrees Fahrenheit (106 degrees Celsius) during the day. Unlike Earth, the Moon does not have a significant atmosphere or magnetic shield to deflect solar wind or trap heat at night, so its temperature fluctuates in its extremes [16]. Therefore, it is impossible to grow plants directly on the Moon's surface with full, unprotected exposure to its natural surroundings.

In order to successfully germinate and grow the seeds she has safely brought to the Moon, a separate dome must be constructed that can withstand cosmic radiation due to the absence of a magnetic field on the Moon. Starting underground will be a wise choice, for underground habitats will protect living organisms from radiation, temperature variation, and other above-ground damages.

Additionally, the ISS frequently uses titanium, kevlar, and high-grade steel (an alloy of iron and carbon). These materials were required by engineers to create a construction that was both light and impenetrable to damage. Minimizing weight is essential since each of the Station's can-shaped metal components must be lifted into orbit. The majority of the modules' outer shell is made of lightweight aluminum rather than heavy steel, and this shell must offer defense against incoming small meteorites and man-made debris. Even grains the size of dust pose a serious threat to the ISS since it travels through space at a speed of around 27,000 km/h. In fact, to ensure the safety of the crew, the Space Station wears a "bullet-proof vest" [17]. Layers of Kevlar, ceramic fabrics, and other advanced materials form a blanket up to 10 cm thick around each module's aluminum shell. (Kevlar is the material used in the bullet-proof vests used by police officers.)

Titanium on the moon is primarily found in the mineral ilmenite, a compound that contains iron, titanium and oxygen. If humans one day mine on the moon, they could break down ilmenite to separate these elements. Furthermore, Apollo data showed that minerals rich in titanium are better at capturing solar wind constituents like helium and hydrogen. [18]. These gases would likely be vital resources in the construction of lunar colonies and for exploration of the moon.

High-grade steel, an alloy of iron and carbon, can be found from extracting hematite. Hematite, a mineral composed of ferric oxide (Fe2O3), has also been found on the moon [19]. This mineral is a product of a reaction between iron, oxygen, and liquid water. Iron can be extracted from hematite (Fe2O3) in a blast furnace.

5. Conclusion

Science has made significant progress to prepare for long-term settlements in space, not only for further space exploration but also for solutions to food insecurity and prevention of the destruction of humanity. For future research, scientists must consider these questions: Can understanding the genes and their alterations in plants help us discover potential solutions to reduce the stress plants receive from lunar soil? Are materials from different areas of the Moon more conducive to plant growth than others? Could studying lunar regolith help us understand more about the Mars regolith and potentially growing plants in that material as well? In essence, people, as a collective group of scientists, astronomers, researchers, companies, and governments, must work together to advance discoveries in this nascent research field.

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