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Soil Based, Aeroponic and Hydroponic Systems in Space with Microgravity and Hypogravity Conditions

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ABSTRACT

Colonizing space in the future is a widely discussed topic in this generation, and sustaining it requires a strong agricultural system in the hypogravity and microgravity conditions. Potential agricultural systems have been considered to be put into action since Tsiolkovsky's works in the early 20th Century. Some of these systems include soil based hydraulics and bioregenerative systems, hydroponic and aeroponic systems which are suitable means to support plants in lower gravity conditions. Testing and data collection on soils and other controls have been done for each method by NASA, Kyushu University etc; and it has been evaluated along with results broadly in terms of input and output factors. The input includes conditions such as water (or medium such as soil), nutrient control, atmospheric control, temperature, humidity and output refers to the yield received. The Controlled Ecological Life Support Systems (CELSS) Program at NASA's Kennedy Space Centre did hydroponic testing that focused on controlled environment production of wheat, soybean, potato, lettuce, sweet potato etc. Further experiments of Silverstone in Biosphere 2 tested the growth of crops in a Martian-like environment that could fulfill the calorie requirement of a four person crew. At Kyushu University, aeroponic nutrient delivery is tested in a microgravity plant growth unit containing radish seeds. The effect of gravity has also been brought about in each method where soil based agriculture loses points due to the toxic gas emissions and suffocation of roots. Even in the comparison of efficiency between aeroponic and hydroponic systems, aeroponic systems are more suitable than soil based space agriculture. A relative weighted comparison between hydroponics and aeroponics reveals that aeroponics is a slightly more efficient system due to higher nutrient control, less space consumption, high nutrient intake, low water requirement, less nutrient wastage, fast growth and germination rate, fewer chances of disease transmission and better utilization of water supply.

Keywords: *Space, Farming, Aeroponics, Hydroponics, Soil Based Bioregenerative Systems, Microgravity, Agriculture, Mars, Moon, Soil, Nutrient Control*

1. INTRODUCTION

Space exploration of mankind in this era has given evidence of the sustainability of life in places other than Earth. For this, extensive research has been done on suitable farming practices which include soil-based, aeroponic, and hydroponic systems in microgravity and hypogravity conditions that affect water flow, nutrient, and oxygen transportation. Adaptation with variable temperatures and atmosphere, LED lighting, and CO2 adjustments come into play with each respective system. The development of these methods in controlled environments increases efficiency to produce food economically with possible expansion of human civilization on Mars and the moon and testing on the International Space Station.

2. SOIL HYDRAULICS AND BIOREGENERATIVE SYSTEMS

Soil-based farming is a suitable approach to sustainable nutrient, water and oxygen flow along with decomposition of organic wastes. Hydraulics and bioregenerative soil systems can provide compactness, low energy requirement, near-ambient reactor pressure and temperature, reliability, the forgiveness of operational errors or neglect (Finstein et al., 1999), and rich biodiversity of microorganisms (e.g., Nelson et al., 2008). These factors are of significant importance, as recognized in recent years, to ensure a long term sustainable life support system in space. [1]

[2][3] However, the effect of hypogravity on these systems still needs to be explored further. Gravity is an important determinant of nutrient and oxygen transportation in liquid and gaseous phases and water flow and hypogravity could in turn lead to toxic gas emissions and suffocation of roots and microorganisms. Lower gravity conditions on the International Space Station (0g), Mars (0.38g), and the moon (0.16g) challenge the physical and biogeochemical processes in the root zone where optimal functionality of plants and microbes is only provided by an adequate supply of water, nutrients, and oxygen. (e.g., Podolsky and Mashinsky, 1994; Porterfield, 2002; Silverstone et al., 2003).

3. TESTING OF SOILS

[4]Lunar regolith and martian dust are suitable alternatives to the soil. However, they would require intensive physical and bio-chemical treatment due to the presence of metals like aluminum and chromium, absence of nitrogen, and high pH levels.

Experiments for testing the soils (on earth) were done Here, small pots filled with 100g moon soil simulant, 100g Earth soil simulant, or 50g Mars soil simulant. 25g demineralized water was added to each one of the pots that were placed in a glasshouse. Different masses of simulants were taken so that every pot had the same volume and column height. There were 3 soils, 14 species of plants, and 20 replicas for each type of soil and plant species totaling up to 840 pots arranged in a completely randomized block design. Every pot held excessive amounts of water in an open petri dish to prevent the growth of roots in other pots.

Both the soils showed germination and growth of the plants, although biomass and germination varied in species and soils.1-low, 2-medium, 3-high

	Earth	Mars	Moon
Germination percentage	2	3	1
Leaf formation	2	3	1
Percentage of plants alive after 50 days	2	3	1
Biomass	2	3	1
Water holding capacity	2	3	1
Organic matter content	3	0	0

All soils also lack nutrients (eg lack of nitrates on the moon soil and lack of phosphates onEarth Soil), which is replenished with nitrogen fixers (which can detoxify the soil from metal pollutants [4] and other minerals can provide a suitable medium for plant growth.

4. SILVERSTONE AND BIOSPHERE EXPERIMENTS FOR MARS [5]

NASA has conducted many experiments that use greenhouses to optimize crop production and hybridize and select improved cultivars. Further testing in Biosphere 2 has been done to test the sustainability of food production on the Martian surface by utilizing local resources minimizing and eliminating the expensive need to resupply materials from the earth.

The soil-based agriculture system on Mars, as proposed by S. Silverstone aims testing bed facilities to reproduce systems that could be used on Mars. It includes the ability to deal with possible emergency situations like crop or mechanical failure in some units. In this experiment, six growing areas (each with ten different crops fulfilling the adequate calorie intake requirement of 4 crew persons) with separate humidity and temperature controls provide optimum ranges for the various kinds of plants being grown in any particular module at any instant of time. Generally, temperatures range from 15.5 - 32.2 degrees Celsius with humidity ranges between 30% -45%.

Table 1. Calculation of Protein and Fat based on a 3000 Kcal/person/day or 12,000 Kcal /4 person crew/day

Crop	%of diet	Kcal/person per day	crop wt/ calorie content (Kcal/g)	grams of crop per day	protein content/gm	protein from crop/day	fat content /gm	fat from crop/day
Rice	15%	450	3.5	128.57	0.13	16.71	0.01	1.29
Wheat	10%	300	3.3	90.91	0.13	11.82	0.02	1.82
Sweet Potato	25%	750	1.06	707.55	0.01	7.08	0.0028	1.98
Peanut	5%	150	5.84	25.68	0.26	6.68	0.48	12.33
Soybean	5%	150	4.02	37.31	0.08	2.99	0.18	6.72
Pinto Bean	10%	300	3.42	87.72	0.24	21.05	0.0086	0.75
Winter squash	7.50%	225	0.634	354.89	0.01	3.55	0.001	0.35
Beet root	7.50%	225	0.445	505.62	0.01	5.06	0.0002	0.1
Banana	10%	300	0.6	500.00	0.006	3.00	0.02	10
Papaya	5%	150	0.26	576.92	0.003	1.73	0.0007	0.40
Total		3000		3015.18		79.66		35.74

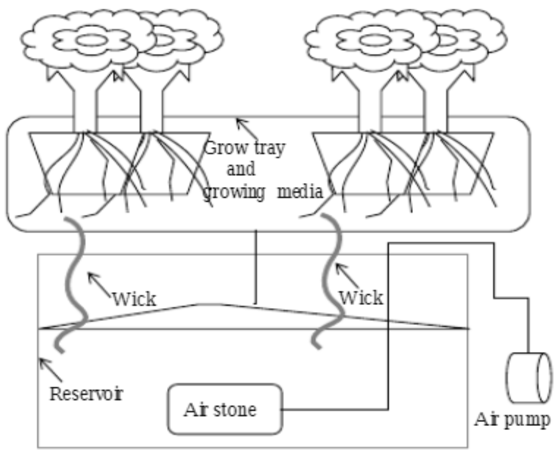
[6] Martian regolith is porous, loosely packed, And contains scectite clays showing that with adequate treatment it can support the growth of plants. For sustainable agriculture on Mars and on the moon, more research still needs to be done so that Martian and lunar soil can provide adequate nutrient growth and recycling of waste materials. Although it is known that hypogravity reduces leaching rates leading to a lower water and nutrient footprint, still a lot is unknown including the further effect of lower gravity conditions, soil-plant dynamics, the exact composition of the soils, and long term resilience of bioregenerative units.

Table 2 Scenario with 50 Einsteins Light.
Design calculations for area of each crop to supply 12,000 Kcal/4 person crew/day

Crop	Kcal for 4 crew daily	Best yield Bio 2 $Kg.m^{-2}d^{-1}$	Light level Bio 2 $mol^{-1}m^{-2}d^{-1}$	Correction factor for 50 $mol^{-1}m^{-2}d^{-1}$	Extrapolated Yield in 50 $mol^{-1}m^{-2}d^{-1}$ $Kg.m^{-2}d^{-1}$	Extrapolated Yield in Kcal/m-2/dy	Area required for feeding 4 crew
Wheat	1200	0.0024	16	3	0.0073	24.38	49.22
Rice	1800	0.0057	25	2	0.0114	40.55	44.39
Sw. potato	3000	0.0160	25	2	0.0320	33.89	88.51
Peanut	600	0.0014	25	2	0.0028	16.32	36.77
Soybean	600	0.0013	25	2	0.0026	10.64	56.41
Pinto Bean	1200	0.0037	25	2	0.0074	25.36	47.32
Beet (root)	900	0.0232	25	2	0.0464	20.45	44.01
W. squash	900	0.0425	25	2	0.0850	54.32	16.57
Banana	1200	0.0498	25	1	0.0498	29.64	40.48
Papaya	600	0.1084	25	1	0.1084	28.68	20.92
	12000						445

Add 33 sq m of salad greens and other leafy vegetables, = 478 m^2
Area of fruit crops (banana + papaya) =61 m^2
Area of field crops in agriculture = 414 m^2

5. HYDROPONIC SYSTEMS IN SPACE



Hydroponics is the cultivation of plants immersed in nutrient solutions, without the use of soil. These systems are very porous and have excellent air retention capacities.

6. CELSS HYDROPONIC SYSTEMS

Controlled Ecological Life support systems are closed ecological systems that are self-supporting in nature and can be suitable systems that can be put to use in future space stations and colonies. NASA is doing intensive research on food production in hydroponic systems for the Control Ecological Life Support System (CELSS), with special attention to light, temperature, CO2 levels, and types of plants to be grown. Experiments are taking place in "closed plant growth chambers " at Kennedy Space Centre where radishes, lettuce, and green onions are being grown hydroponically under controlled conditions. Comparisons are being made to grow plants in "mixed cultures" rather than in "monocultures" and in lower pressure environments for better visibility and fewer leaks.

6.1 Experiments conducted in CELSS at National Administration of Space and Aeronautics:

[8]Crops like potatoes, wheat, peanut, sugar beets and sweet potatoes which have subsurface edible parts have been grown in CELSS. They have been grown in open and closed, solid media and liquid hydroponic systems. Light sources such as fluorescent incandescent high-pressure sodium and metal halide lamps in combination with moderate temperatures round the clock have produced a significant crop output.

[9] The Biomass Production Chamber at NASA's CELSS grew and analyzed the following crops: wheat, lettuce, potato, and soybean. Soybean showed the highest percentage of protein and fat, while potato and wheat had the highest levels of

carbohydrate. Lettuce contained the maximum level of ash. When we compared these crops with field-grown variants, they showed nutrient value broadly similar with some exceptions. Wheat had higher protein levels, soybean had more ash and crude fiber, potato and lettuce had more protein than the field variety. The higher ash and protein levels could be because of the continuous supply of nutrients to the crops through hydroponic culture

6.2 NASA's Life Support System to grow wheat in extraterrestrial colonies [10]

A crop selected NASA for a selected CELSS unit in extraterrestrial colonies is wheat. One meter cube of actively growing wheat provides enough oxygen for one person. 6 kilos of wheat in a cubic meter, over a period of 60 days.

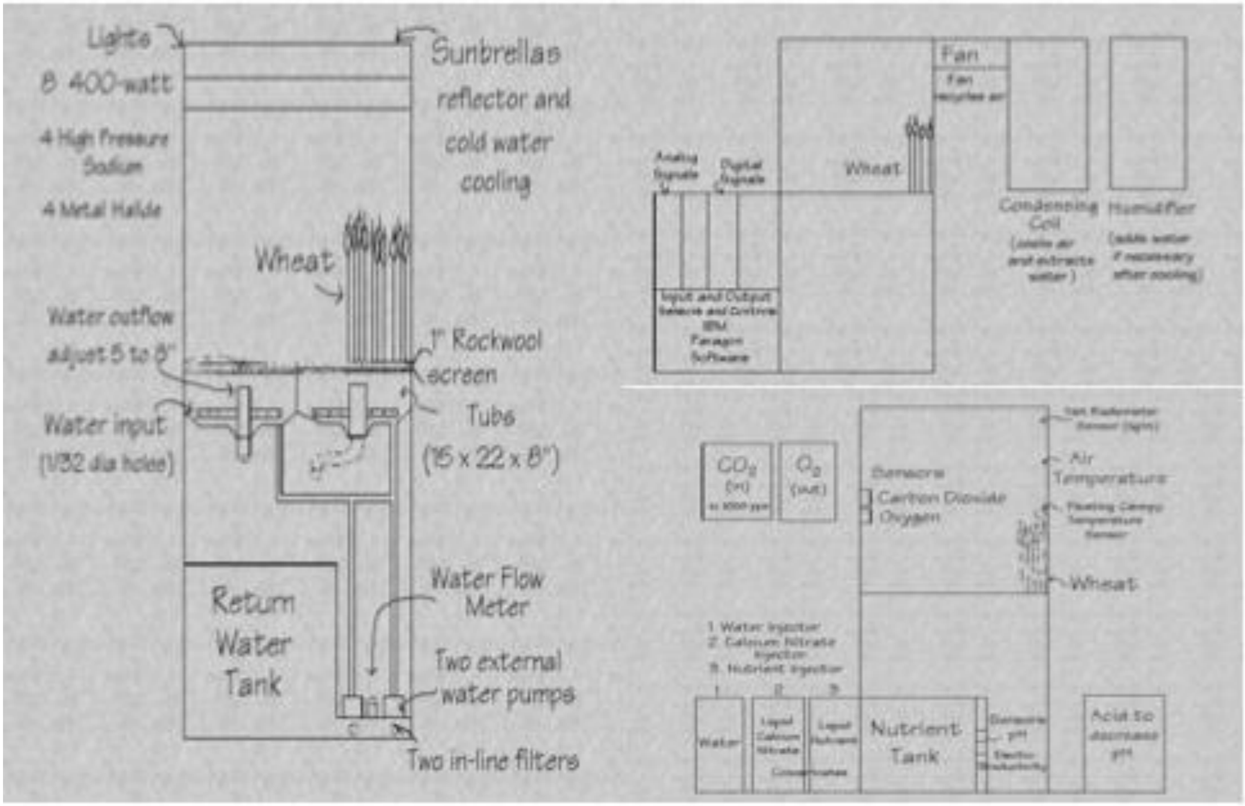
Computer Control System: operated on an IBM PC using Paragon software.

Gases: CO2 and O2 are monitored by the control system in the chamber.

pH: Cole-Palmer's epoxy covered sensor is used as the pH sensor here. Injection pump controlled pH and sulfuric acid (H2SO4) or phosphoric acid (H3PO4) is used to reduce pH.

Conductivity and Temperature: Conductivity changes with temperature so measurements are to be taken at 25 degrees C.

Working:



- Eight lights(four 400 watts high-pressure sodium and four 400 watts metal halide.) on the roof that functions all day and night to produce 1300 micromoles of photons per m2 per second.
- Densely packed trays of wheat (2000 plants/meter)have a sloping bottom with a center overflow valve in which nutrient pump is introduced.
- The growth of roots takes place in Rockwool and grid plate to the water tank
- The bottom layer includes a return water tank below the nutrient tanks above to maintain oxygen levels.
- Two external water pumps(1/8 horsepower TM 90 Little Giant pump) that supply nutrient water to the 4 plant tanks above.
- The Dayton Electric filters in front of the water line take out stray root matter and rock wool.
- Flowmeter Fisher Signet 3-8500 is set to alarm the computer system when the flow decreases to a certain rate of about 10 l/m^2min.
- When the flow drops to that set point the computer shuts down the entire CELSS unit, lights pumps, and circulation of air.

7. OMNI-GRAVITY SYSTEMS FOR A SPACECRAFT[11]

Omni-gravity hydroponics helps astronauts meet their supplementary nutrition needs and also complete the cycle of water in orbit, lunar, and Mars. The project determines the operational limits of the test cells for the Plant Water Management Hydroponics mission. Rihana Mungin designed a scaled 1-g channel to replicate the full-scale performance in microgravity, which one could test on earth. This project attempted to discover the limits of operation of 1-g test cells and point out failures that would be risky in space.

[11] In figure 1, many key limits were found which could be represented as a function of logarithmic flow rate and fill percentage. The downstream profile of the liquid, at lower fills, had reached bubble ingestion as the rate of flow increased (at the outlet). Embolisms were formed on the upstream free surface when the flow was high at higher fills. This in turn indicated instability. Additionally, in some of the configurations, inertial forces overcame capillary forces which resulted in mass ejections. The stable limits of operating have decreased drastically as the flow was disrupted in the plants.

In the test, new stability regimes were identified, indicating that the phenomenon is independent of the effects of gravity. In the system, as plants are introduced, the flow is diupted by the roots even further and this causes droplet ejections at flow rates that are comparatively lower.

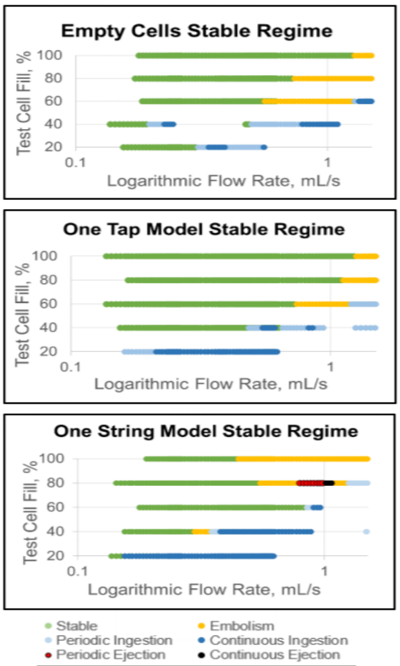
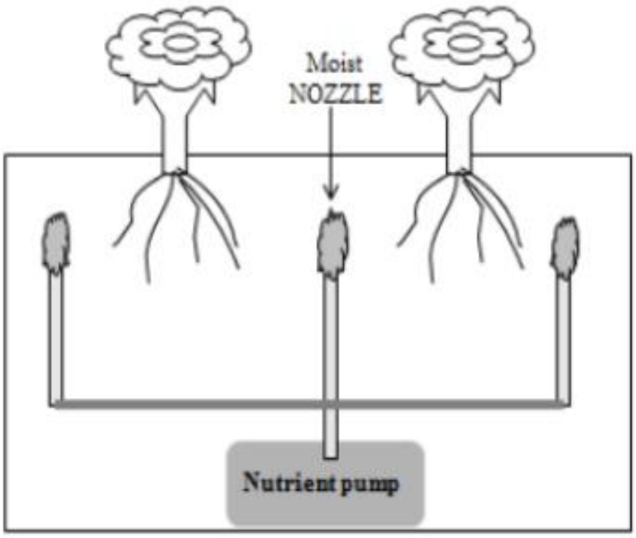


Figure 1: Stable operation regimes for cells tested with 0 plant models, 1 tap model, and 1 string model. Regimes include bubble ingestion, embolism formation, and mass ejection.

8. AEROPONIC SYSTEMS IN SPACE



[7]Aeroponics (a subset of hydroponic systems) is a system where plant roots are continuously or discontinuously in a saturated condition with fine drops (a mist or aerosol) of nutrient solution. It requires no substrate and allows growing plants with roots wetted periodically with a fine mist of atomized nutrients.

[12] Aeroponics systems can maximize crop yields and reduce water usage by 98 percent, fertilizer by 60 percent, and pesticide the usage of pesticides 100 percent. Plants grown in the aeroponic systems have shown higher nutrient, vitamin, and mineral uptake, making the plants healthier and nutritious.

[13] Aeroponics has some significant advantages over soil-based cultivation. In the case of diseases, it is easy to isolate and remove the plant since there can be no transmission through the soil system. Aeroponically grown plants also grow faster since the roots are exposed directly to the nutrient solution leading to faster absorption than through the soil medium. In the recirculation mode, aeroponics also requires less water than soil-based cultivation. It can also help save space through nutrient delivery to vertically stacked plants. Given that it is more efficient in the management of space, water and nutrient absorption, aeroponics is a great system for urban agriculture where space and water are at a premium. These attributes are also useful in space, In addition, a reason to use aeroponics in space is that it can work as efficiently in 1-g as well as in microgravity.

In the late 1990s, Ricard Stoner used NASA's funding to develop Aeroponic systems in low in space. In low gravity conditions, aeroponic systems are the most effective systems with excellent aeration and nutrition capabilities for the plants. It makes efficient use of water, requires no growing medium and utilizes minimum storage, NASA states and aeroponics may be an essential part of future space exploration with an emphasis on the moon and Mars

9. MIR STUDY AND BIOCONTROLS [14]

In 1997, NASA studied Adzuki bean seeds and seedlings aboard the Mir space station. The crop was compared with a control set of the same crop grown on earth, Both the sets of plans were treated with a disease control solution called Organic Disease Control or Organically Derived Colloidals. While both the groups grew well, the seeds and seedlings aboard Mir station grew more than those on Earth. Both the sets treated with the ODC exhibited a lesser tendency for fungal infections.

10. AIRFLOW-CONTAINED AEROPONIC NUTRIENT DELIVERY FOR A MICROGRAVITY PRANT GROWTH UNIT[15]

Tests were done at Kyushu University, Japan to test Aeroponic nutrient delivery in a microgravity plant growth unit. A system was set up to grow 18 radish seeds in seed holders.

10.1 Assumptions

To verify the containment of nutrient solution, it had to be assumed if the system was successful when gravity could cause leakage, it would also be successful in microgravity where the leakage is only caused by surface tension.

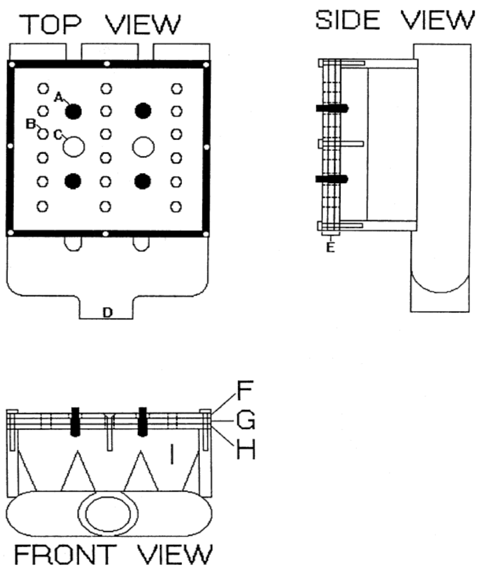


Fig. 1. Plant growth unit that uses induced air flow to contain nutrient solution. A. Nutrient nozzle. B. Seed holder port. C. Air flow inlet. D. Air and nutrient solution outlet. E. Three layer root plant. F. Top plate. G. Air space. H. Bottom plate. I. Root chamber.

To test the ability of the system to germinate and grow plants, another assumption had to be made that if gravity(during germination) strongly influences orientation, it could be temporarily produced in microgravity as well. The results of the experiment proved to be particularly sensitive to the type of seed holders used.

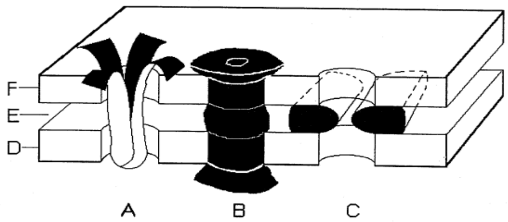


Fig. 2. Seed holder configurations tested in the plant growth unit. A. Filter paper Seed holder. B. Sponge Seed holder. C. Neoprene Seed holder. D. Top plate. E. Air space. F. Bottom plate.

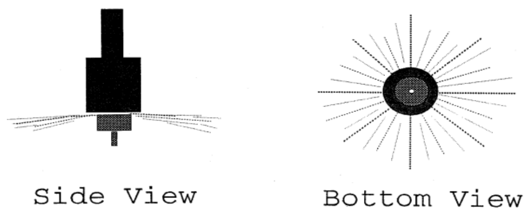


Fig. 3. Nozzles with 360° horizontal spray pattern.

This test resulted in 77% germination and some growth.The first important result that was seen was that the nutrient solution was completely contained within the unit in any orientation with respect to gravity. Thus, the airflow was able to counteract both surface tension and gravity. It was difficult to test the germination ability and growth since there was sensitivity to the seed holder type and seed viability. Both germination and growth were heavily dependent on the seed holder configuration and material. To conclude, we can be reasonably certain that this system will produce significant yield and will be able to contain the solution in microgravity

11. CONCLUSION

A COMPARISON BY HYDROPONIC VS AEROPONIC SYSTEMS

TRADE STUDY ON GROWING METHODS											
Criteria [c1]	**Nutrient control**	**Space consumption**	**Nutrient intake**	**Water requirement**	**Cost**	**Nutrient Wastage**	**Growth rate**	**Disease Transmission**	**Droplet size**	**Water Supply**	**Total**
Scale	4-High nutrient control 1-Low nutrient control	4-Low consumption 1-high consumption	4-Maximum nutrient intake 1-Minimum nutrient intake	4-Low water requirement 1-High water requirement	4-Low cost 1-High cost	4-Less waste 1-High wastage	4-Fast growth rate 1-Slow growth rate	4-Less chances of disease transmission 1-High chances of disease transmission	4-Small 1-Big	4-Supply is not required at all times 1-Constant supply is required	Σ(c1w1)
Weightage(in percentage) [w1]	5	10	10	10	20	5	15	10	5	10	100
HYDROPONICS	4	1	2	1	3	3	2	1	1	2	200
AEROPONICS	3	3	3	3	2	2	3	3	3	1	255

All systems- bio regenerative soil systems, aeroponics, and hydroponics are appropriate scientifically and feasible to support plant life in hypogravity or microgravity conditions. However, hydroponic and aeroponic systems are more effective and have a significant edge over soil-based systems. When it comes to comparing both the soil-less agricultural systems, minor differences in certain factors can be observed. After weighing the scores considering all the experiments done by researchers and scientists previously, the aeroponic systems scored the most (255 points). Hence if ever, future space colonies require a food growing system, aeroponics will be the most suitable system due to higher nutrient control, less space consumption, high nutrient intake, low water requirement, less nutrient wastage, fast growth and germination rate, fewer chances of disease transmission and better utilization of water supply.

11. REFERENCES

[1] Finstein, M.S., Strom, P.F., Hogan, J.A., Cowan, R.M., 1999. Composting on Mars or the Moon: I. Comparative evaluation of process design alternatives. Life Support and Biosphere Science 6, 169–179.

[2] Nelson, M., Dempster, W.F., Allen, J.P., 2008. Integration of lessons from recent research for ‘‘Earth to Mars’’ life support systems. Advances in Space Research 41, 675–683.

[3] Federico Maggi a,n, Ce´line Pallud: Space agriculture in micro- and hypo-gravity: A comparative study of soil hydraulics and biogeochemistry in a cropping unit on Earth, Mars, the Moon and the space station

[4] Podolsky, I., Mashinsky, A., 1994. peculiarities of moisture transfer in capillary- porous soil substitutes during space flight. Advances in Space Research 14 (11),

[5] Scovazzo, P., Illangasekare, T.H., Hoehn, A., Todd, P., 2001. Modeling of two-phase flow in membranes and porous median microgravity as applied to plant irrigation in space. Water Resources Research 37 (5), 1231–1243.

[6] Wamelink GW, Frissel JY, Krijnen WH, Verwoert MR, Goedhart PW. Can plants grow on Mars and the moon: a growth experiment on Mars and moon soil simulants. PLoS One. 2014;9(8):e103138. Published 2014 Aug 27. doi:10.1371/journal.pone.0103138

[7] Silverstone S, Nelson M, Alling A, Allen J. Development and research program for a soil-based bioregenerative agriculture system to feed a four-person crew at a Mars base. Adv Space Res. 2003;31(1):69-75. doi:10.1016/s0273-1177(02)00661-0

[8] TY - JOUR AU - Silverstone, Sally AU - Nelson, Mark AU - Alling, Abigail AU - Allen, John PY - 2005/02/01 SP - 1544 EP - 51 T1 - Soil and crop management experiments in the Laboratory Biosphere: An analog system for the Mars On Earth (R) facility VL - 35 DO - 10.1016/j.asr.2005.06.008 JO - Advances in space research : the official journal of the Committee on Space Research (COSPAR) ER -

[9] TY - JOUR AU - Lakkireddy, Kiran AU - Kondapalli, Kasturi AU - Sambasiva Rao, K.R.S. PY - 2012/04/01 SP - Pages 26 EP - 35. T1 - Role of Hydroponics and Aeroponics in Soilless Culture in Commercial Food Production VL - Volume 1

[10] JO - Research & Reviews: Journal of Agricultural Science and Technology (RRJoAST) ER -

[11] Hill WA, Mortley DG, Mackowiak CL, et al. Growing root, tuber, and nut crops hydroponically for CELSS. Adv Space Res. 1992;12(5):125-131. doi:10.1016/0273-1177(92)90018-s

[12] Wheeler RM, Mackowiak CL, Sager JC, Knott WM, Berry WL. Proximate composition of CELSS crops grown in NASA's Biomass Production Chamber. Adv Space Res. 1996;18(4-5):43-47. doi:10.1016/0273-1177(95)00860-h

[13] http://www.carbon.org/school/newclass/nasa.htm

[14] Omni-gravity Hydroponics System for Spacecraft, Tara M. Prevo, Dryden Drop Tower

[15] https://www.nasa.gov/vision/earth/technologies/aeroponic_plants.html

[16] Astro GardenTM Aeroponic Plant Growth System Design Evolution Sam A. Moffatti , Robert C. Morrowii, and John P. Wetzeliii Sierra Nevada Corporation, Madison, WI, 53717, USA

[17] https://www.advancednutrients.com/articles/aeroponics-and-nasa/

[18]]https://www.advancednutrients.com/articles/aeroponics-and-nasa/

[19] AIRFLOW-CONTAINED AEROPONIC NUTRIENT DELIVERY FOR A MICROGRAVITY PRANT GROWTH UNIT Hessel, M. I. Jr. Department of Aerospace Engineering Mechanics and the Engineering Science University of Florida Richert, G. E. Jr. Department of Aerospace Engineering Mechanics and the Engineering Science University of Florida Nevill, G. E. Jr. Department of Aerospace Engineering Mechanics and Engineering Science University of Florida

