Hydroponic: A Study of Space Farming

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Abstract
This paper demonstrates the possibility of supporting human life in space, by growing fresh vegetables and producing them through simulated growing conditions. Supplying fresh vegetables to space stations and manned space missions is complicated and prohibitively expensive. Growing plants can be tough in space because of zero gravity, unavailability of soil, fertilizers, etc. Hydroponic is an advanced technology for growing plants without using natural resources (i.e. soil, air, natural fertilizers, etc.). It is a combination with greenhouses, it is advanced technology and highly intensive. The hydroponic technology takes place inside the enclosures to control air, temperature, and humidity using a vapor pressure deficit (vpd) controller, nutrient flow, and water flow controller. A major concern is the micro-gravity, which causes roots to grow differently than those from earth farming. In microgravity and hypo-gravity conditions, space farming utilizes a variety of methods like hydroponics, aeroponics, etc. This paper focuses on the hydroponics design, structure, operations, technique, substrate suitable for the plants, pH values, water level, and controllers required for hydroponic technology. The main objective of the paper is to build a preliminary design that is completely automatic that is robust and foolproof and find the definitive solution to the problems in the substrate and multi-spectrum lighting aroused due to gravity and vacuum conditions. The fully automated systems help to the reduction of labor and provide good healthy food to astronauts.

Keywords: Hydroponics, space farming, astronauts, plants, Nutrients, vapor-pressure deficit controller

I. Introduction

Due to the cost-effectiveness of resupplying in space missions, growing vegetables in space is an incredible potential. The presence of a space farm would contribute to creating a natural environment since plants can be used to recycle wastewater, generate oxygen, and purify air continuously. In addition to a large portion of their weight in their spacecraft, astronauts are required to carry canned space food, which is low in nutrients and vitamins in astronauts' diets. Fresh vegetables with enhanced taste and quality could be produced in space through space farming and would reduce the vitamin deficit in astronauts' diets. By converting a spaceship into an artificial ecosystem with a hydrological cycle and nutrient recycling, space farming could become a reality.

The capacity to regularly feed a crew with oxygen, water, and food while requiring little replenishment from Earth will determine whether or not space can be colonized. Plant crops are grown on Earth to support these tasks, hence creating plant-based food production systems is crucial to maintaining humankind's existence in space. Gravity also influences the flow of heat, water vapor, CO_2, and oxygen between the surfaces of plants and their surroundings. Due to the lack of buoyancy-dependent convective transport, larger boundary layers around plant organs and decreased mass transfer may potentially have an impact on these processes in microgravity. To survive in microgravity, high and low ambient temperature extremes, decreased atmospheric pressure, atmospheres with high volatile organic carbon contents, and raised to super-elevated CO_2 concentrations, future space farmers will need to modify their farming methods [1]. The authors used a brand-new hydroponic method to grow sweet potatoes' tuberous roots as well as their fresh, edible leaves and stems. The first experiment looked at how the water content of the rooting substrate affected the sweet potato's growth and tuberous root formation. The rooting substrates consisting of slabs of rock wool were angled within a culture container, allowing capillary action to draw nutrient solution up from the bottom end of the slabs. On the underside of the rockwool slabs, tubercles sprouted. The lower the water content in the rockwool slabs, the farther away from the water's surface the better the growth and development of the tuberous roots. In the second experiment, three cultivars of sweet potatoes were grown in a hydroponic system in Osaka, Japan, for five months between June and November in the sun. This study served as a foundation for the development of the space farming system [2].

The saturation point of soil fertility has been reached, and more fertilizer application does not result in further production increases. The production of food under conventional soil-based agriculture is also threatened by factors such as poor soil fertility in some cultivable areas, decreased likelihood of natural soil fertility build-up by microbes due to continuous cultivation, frequent drought conditions, the unpredictability of climate and weather patterns, rise in temperature, pollution in rivers, poor water management and massive water waste, decline in groundwater level, etc. The saturation point of soil fertility has been reached, and more fertilizer application does not result in further production increases. The production of food under conventional soil-based agriculture is also threatened by factors such as poor soil fertility in some cultivable areas, decreased likelihood of natural soil fertility build-up by microbes due to continuous cultivation, frequent drought conditions, the unpredictability of climate and weather patterns, rise in temperature, pollution in rivers, poor water management and massive water waste, decline in groundwater level, etc. [3]. According to the authors' analysis, three primary questions are taken into account: what are the different hydroponic vegetable gardening techniques compared to traditional (soil) gardening methods; what is the present and anticipated cost of hydroponics farming; and is there any public perception of hydroponics that could affect people's willingness to use or participate in the practice? The paper's conclusions and outcomes apply to individuals worldwide, indicating that, contingent on the scale of the enterprise, households might produce a dependable food supply on their own. It is hoped that this paper will expound on a realistic and effective solution for feeding people, given the ever-increasing human population. It also raises the possibility of being a way to grow food for space flight [4].

This work created a smart hydroponics system that uses precise inference in a Bayesian network (BN) to automate the crop-growing process. Installed to monitor and regulate physical events including light intensity, pH, electrical conductivity, water temperature, and relative humidity are sensors and actuators. The Bayesian Network was constructed using the collected sensor values to get the ideal value for every parameter. A web interface is created so that the user may utilize the Internet to remotely monitor and manage the farm [5]. Scientists have shown that hydroponic plant systems require fewer inorganic materials for plant growth than soil-based systems, provided they have access to water, oxygen, and sunlight. India's agriculture may benefit greatly from hydroponics since it can grow crops without soil in every season. Even on small, fragmented farms, these techniques can assist Indian farmers in increasing the productivity of their crops. This review study focuses on the difficulties and opportunities associated with introducing soil-less farming to India to maintain its stability and enable Indian farmers to produce crops that are entirely organic, toxic-free, and of higher quality [6]. Underdevelopment and poverty are mostly caused by geographical factors and reliance on agricultural production in India. These can be accomplished using cutting-edge farming techniques like hydroponics. This project aims to create a completely automated hydroponic system that can be incorporated into the agricultural curriculum and teaches business skills [7].

To determine which farming system will best meet present and future demand while consuming the fewest resources and costs, this article compares two farming systems. The conventional soil-based system is the first, while the hydroponic system is the second. Cucumber and Armenian cucumber seeds were the two varieties utilized. The plant heights for both systems were measured over 30 days. Following data collection, Design-Expert and the variance test (ANOVA) were used to analyze the data. The test's hypothesis is whether or not the kind of seeds used, the planting method, and their combination affect the plant's height. The investigation revealed that there is no discernible relationship between seed type and plant development [8]. This study set out to ascertain the impact of several parameters on the training and research viability of hydroponic agriculture. Using the census method, 176 experts in the Agricultural Ministry made up the research population. This study was conducted using a descriptive-correlation methodology. A panel of specialists, including senior faculty members and research committee advisors, determined the validity of the instrument [9]. In such circumstances, a system that can support plants and make the best use of available space is required. Urban residents frequently lack the time necessary to care for their plants, so automated (or remotely monitored) systems can support urban agriculture (such as hydroponics) and other living spaces [10]. A hygienic and natural diet is sometimes necessary for astronauts traveling in spacecraft with rocket engines, such as liquid, hybrid [11-13], or solid rocket motors [14-15]. They are able to meet their food needs by using hydroponic technology.

The purpose of this review is to examine the advantages and disadvantages of hydroponic solutions for soilless cropping systems, with a particular emphasis on the process of plant mineral nutrition. With specific reference to crop quality, this review offers information (1) on the mechanisms and processes that occur in hydroponic solutions to guarantee an appropriate concentration of nutrients and, consequently, an optimal acquisition of nutrients without causing nutritional disorders (e.g., solubilization/precipitation of nutrients/elements in the hydroponic solution, substrate specificity in the nutrient uptake process, nutrient competition/antagonism and interactions among nutrients); (2) The use of nanoparticles and beneficial microorganisms like plant growth-promoting rhizobacteria (PGPRs) are new emerging technologies that may improve the management of soilless cropping systems. (3) including multi-element sensors and machine learning-based interpretation algorithms to analyze such data, may be used in a smart agriculture approach to monitor the availability of nutrients and other elements in the hydroponic solution and to change its composition in real-time [16].

Today, hydroponics, a soilless cultivation method, promises to deliver high-quality, healthy, fresh, residue-free vegetables and fruits locally to combat the multi-manifestations of climate change, freshwater scarcity, and the pressing requirement of the expanding food demand. This review sheds light on the advantages and disadvantages of the hydroponics industry. Along with the present trend prevailing in it and an outline of the major companies dealing in the same, it also highlights the expertise required to undertake hydroponics growth [17]. Two common wetland plants were used in hydroponic growing systems to treat simulated high-sulfate wastewaters: lucky bamboo (Dracaena sanderiana) and Pampas grass (Cortaderia selloana). When comparing the same experimental circumstances at pH 6.0 to pH 7.0, plants in the early experiments eliminated sulfate more effectively. Findings from three consecutive 7-day treatment periods with 1-day rest intervals at sulfate concentrations of 50, 200, 300, 600, 900, 1200, 1500, and 3000 mg/L demonstrated declining trends in both removal efficiencies and uptake rates with increasing sulfate concentrations from the first to the second to the third 7-day treatment periods [18].

Describing the lighting system issues, the physical restrictions and energy needs for ISS farming with space and energy resources, and the standards for choosing plants fit for microgravity and space farming. Although it is evident that the size of growth hardware that can be installed on the International Space Station (ISS) does not permit the production of enough fresh food to supplement the astronauts' packaged, stored diet, ISS experimentation is essential for the implementation of plant growth systems and opens the door for future long-duration space missions, such as those to the lunar surface and cis-lunar space [19]. The purpose of this study was to examine the effects of mixing decorative plants with different types of growing media in an indoor green wall system on air quality performance. The growing media types comprised cocopeat, perlite, cocopeat + perlite (1v:1v), and cocopeat + perlite + vermicompost (1v:1v:1v), which were combined based on volume %. Peperomia magnoliiaefolia, Aptenia cordifolia, Kalanchoe blossfeldiana, and Carpobrotus edulis were among the decorative plants. To increase plant development and morphophysiological parameters, there were notable discrepancies between the plant species and growing media types. An internal green wall that is horticulturally sustainable can be made by combining vermicompost, perlite, and cocopeat with Aptenia cordifolia as the species. This will also raise the interior environments of the buildings' health index [20]. Create a system in this task that combines solar energy, hydroponics, and fuel cell technology breakthroughs. The created system was successfully implemented in the farming industry, leading to a sharp rise in urban farming and improvements to conventional rural farming practices. The implementation of automation in this hydroponic system will enhance yield consistency monitoring. The system's carbon impact is decreased via the use of solar power and fuel cell technology [21].

Hydroponics is divided into different systems according to its guiding principles. Many facets of plant biology research have adopted hydroponics as a mainstream technique, utilizing a variety of systems, automation, and operation management techniques. Hydroponics has other benefits beyond only encouraging healthy plant development, such as year-round production, improved yields, quality, and environmental advantages. Hydroponics has been used extensively in studies to study how plants react to both biotic and abiotic stimuli. This agricultural system is a promising solution to the global food security dilemma, and it will help progress technology to make it a self-sustaining model for future generations [22].

There is not much ease in growing food in space. A significant point is the lack of gravity, which causes roots to grow differently than those from earth farming. In microgravity and hypo-gravity conditions, space farming utilizes a variety of methods like aeroponics, hydroponics, and soil-based farming. These operations affect water flow, and nutrient and oxygen transportation. To increase the efficiency of producing vegetables economically, scientists/researchers would like to adopt variable temperature controllers, artificial lighting, and a controlled CO_2 environment to improve the efficiency of the plant.

II. Methodology

Hydroponic cultivation represents a groundbreaking approach to growing plants that dispenses with traditional soil and instead relies on water to transport essential nutrients directly to the plant roots. This method has gained prominence in modern agriculture and horticulture, particularly when incorporated within controlled environments like greenhouses. The detailed explanation with various advantages is as follows:

Soilless Growth: Hydroponics is characterized by its soilless nature. Plants are cultivated in an environment where the reliance on natural soil is eliminated. Instead, they are placed in an inert growing medium that could be composed of materials such as perlite, vermiculite, coconut coir, or even just a nutrient-rich water solution. By circumventing the use of traditional soil, this method offers several advantages. It allows for precise control over the nutritional intake of plants, as well as their exposure to light, temperature, and humidity. This level of control is not readily achievable in traditional agriculture.

Direct Nutrient Exposure: One of the defining features of hydroponics is the direct exposure of plant roots to a nutrient solution. This means that the plant's roots are submerged or irrigated with a carefully balanced mix of essential nutrients dissolved in water. This direct access to nutrients allows plants to absorb the required elements more efficiently, resulting in accelerated growth rates compared to conventional soil-based cultivation. Additionally, because the nutrients are readily available, the risk of nutrient deficiencies or imbalances is significantly reduced.

Controlled Environment: Hydroponic systems are often integrated into controlled environments, most notably greenhouses. The purpose of this enclosure is to exert precise control over various environmental parameters. These parameters include air quality, room temperature, light intensity and duration, humidity levels, and the availability of water and nutrients. Such meticulous control enables year-round cultivation, independent of external weather conditions, and optimizes plant growth. Moreover, it mitigates the influence of pests and diseases, reducing the need for chemical interventions.

High Technology: Hydroponic systems are at the forefront of agricultural technology. They incorporate sophisticated automation and monitoring systems that manage nutrient delivery, environmental conditions, and data-driven decision-making. Sensors continuously measure and adjust factors like pH levels, nutrient concentration, and temperature to ensure that plants receive precisely what they need for optimal growth. These high-tech features not only maximize efficiency but also reduce resource wastage, making hydroponics an environmentally friendly farming method.

Space Agriculture: One of the most intriguing applications of hydroponics is in space agriculture. In the challenging environment of space, maintaining a breathable atmosphere and providing sustenance for astronauts during long-duration missions are paramount concerns. Hydroponic systems offer a bio-regenerative solution to these challenges. Plants, through the process of photosynthesis, generate oxygen, thereby contributing to life support systems. They also provide fresh food, which is a psychological boon to space travelers, offering a semblance of home and familiarity in an otherwise inhospitable setting. The combination of oxygen production and food generation in closed-loop systems can significantly enhance the well-being of astronauts on extended missions.

Nutrient Film Technique (NFT): The Nutrient Film Technique (NFT) is a widely adopted hydroponic method, particularly in space agriculture. In NFT systems, a thin, shallow film of nutrient-rich water continuously flows through channels or troughs. Plant roots are suspended within these channels, with their root systems making direct contact with the nutrient film. This approach ensures a consistent and continuous supply of essential nutrients while also providing aeration to the roots, preventing waterlogging, and ensuring optimal oxygen uptake. The efficiency of NFT in nutrient and water usage makes it an ideal choice for space cultivation where resources are limited and must be conserved.

In short, hydroponic cultivation is a revolutionary and highly efficient method of plant growth that eschews traditional soil-based farming. When paired with controlled environments such as greenhouses, it empowers growers with unprecedented control over growth conditions, leading to enhanced yields and resource efficiency. Additionally, hydroponics plays a pivotal role in space agriculture by providing oxygen and food to astronauts, thereby promoting their physical and psychological well-being during prolonged missions. The Nutrient Film Technique exemplifies one of the many innovative hydroponic methods, showcasing the adaptability and versatility of this technology across different contexts.

Challenges in space : Artificial lighting, microgravity, and extreme temperature fluctuations are fundamental challenges that must be addressed to successfully cultivate plants in the unique environment of space. To overcome these challenges, researchers and engineers have developed sophisticated solutions, including the utilization of LED lighting systems, ceramic porous tubes for watering, and the implementation of robot farms. In this detailed elaboration, we will delve into the intricacies of each of these solutions and their role in enabling space agriculture.

Artificial Lighting: In space, natural sunlight is scarce or absent, making it necessary to rely on artificial lighting systems for plant growth. LED (Light Emitting Diode) technology is the illumination method of choice due to its numerous advantages. LEDs offer exceptional energy efficiency, long lifespan, and the ability to fine-tune the light spectrum. Plants require specific wavelengths of light for photosynthesis, and LEDs can be precisely adjusted to provide the optimal combination of blue and red light for different growth stages. This tunability allows researchers to mimic natural light conditions and optimize plant growth. Furthermore, LEDs are adaptable to various plant species, ensuring that each receives the light conditions best suited to its requirements throughout its growth cycle, from seed germination to flowering.

Microgravity: Cultivating plants in microgravity or reduced gravity presents a significant challenge, primarily in the context of delivering water and nutrients to plant roots. Traditional methods, such as soil-based cultivation or hydroponic systems that rely on gravity to transport water, are not feasible in the absence of gravitational force. To address this issue, ceramic porous tubes play a pivotal role. These tubes are designed to facilitate capillary action, enabling water to be drawn upward through the porous material to reach the plant roots. This capillary system operates without the need for gravity and ensures that plants receive a controlled and efficient supply of water and nutrients. It's a highly effective solution for providing essential resources to plants in microgravity.

Extreme Temperatures: Space environments are characterized by extreme temperature fluctuations due to factors such as radiation exposure and the absence of atmospheric insulation. These temperature swings can be detrimental to plant growth and overall crop health. To combat these challenges, thermal insulation and temperature control systems are integrated into the plant cultivation environment. Insulating materials serve to maintain a stable internal temperature within the growth chamber, shielding plants from abrupt temperature changes. Moreover, thermal regulation systems, which can include heating and cooling elements, are employed to actively control the temperature within the growth chamber. This ensures that plants are consistently exposed to temperature conditions that fall within the optimal range for their growth and development.

Robot Farms: Robot farms represent the pinnacle of technology in space agriculture, designed to create a fully autonomous and controlled growth environment for plants. These systems rely on a combination of sophisticated sensors and automation to manage critical growth parameters. Here's an in-depth look at how robot farms function:

- **Light Control:** Robot farms are equipped with a network of sensors that continuously monitor the light conditions in the growth chamber. Based on the specific requirements of the plants and their growth stages, the system adjusts the intensity and spectrum of artificial lighting to optimize photosynthesis and promote robust plant growth.
- **Temperature Control:** Similar to light control, sensors constantly track temperature within the growth environment. If the temperature deviates from the ideal range for plant growth, the system can promptly activate heating or cooling elements to restore optimal conditions.
- **Oxygen Levels:** Robot farms also incorporate sensors to monitor oxygen levels. This information allows the system to make necessary adjustments to ventilation or oxygen injection to ensure a suitable atmosphere for plant respiration and to meet the oxygen needs of astronauts within the space habitat.
- **Nutrient Supply:** In conjunction with hydroponic or aeroponic systems, robot farms efficiently provide plants with a controlled supply of nutrients. The concentration of nutrients can be dynamically adjusted to match the requirements of the plants at different growth stages.

Robot farms operate autonomously, enabling continuous plant growth without the need for direct human intervention. These systems are indispensable for long-duration space missions as they will not only provide a sustainable source of fresh food and oxygen but also contribute significantly to the psychological well-being of astronauts by creating a sense of familiarity and normalcy within the otherwise unfamiliar and challenging environment of space.

The solutions of artificial lighting, ceramic porous tubes, insulation, and robot farms collectively address the multifaceted challenges of space agriculture. By combining these innovative technologies, space researchers and agencies can ensure that plants grow successfully in space, supporting the sustainability and well-being of astronauts on extended missions. These advancements represent a critical step in achieving self-sufficiency in space habitats and exploring the possibilities of human presence beyond Earth.

Methods of Hydroponics: Two types of techniques of hydroponic cultivation are classified based on the type of cultures. The types of cultures are as follows:

*** Solution Culture:** In a solution culture, plant roots are suspended directly in the nutritional solution. It can be further divided into the following categories:

Circulating methods/ Continuous-flow solution culture: It is a closed system, and it has also two types:

- Deep Flow Technique (DFT)
- Nutrient Film Technique (NFT)

The solution culture systems can keep nutrients flowing to the roots at all times. They are particularly vulnerable to automatic control, but they suffer severe dehydration if the nutrient solution flow is interrupted for any reason.

Non-circulating methods/ Static Solution Culture: It is an Open System, and it has three different types:

- Floating Technique
- Root Dripping Technique

- Capillary Action Technique

The solution culture systems use static flow. Glass jars or containers wrapped in black polythene film, polyethylene beakers, pots, and other vessels are ideal for these types of static flow systems.

Media Culture

The media culture is a method for planting roots in a solid medium, and it is named after several types of inert mediums such as sand, gravel, or rock–wool cultures. Sub-irrigation and top-irrigation are two different methods of irrigation that are used depending on the culture type.

However, media culture can be further divided into the following categories:

- Hanging Bag Technique
- Grow Bag Technique
- Trench or Trough Technique
- Pot Technique

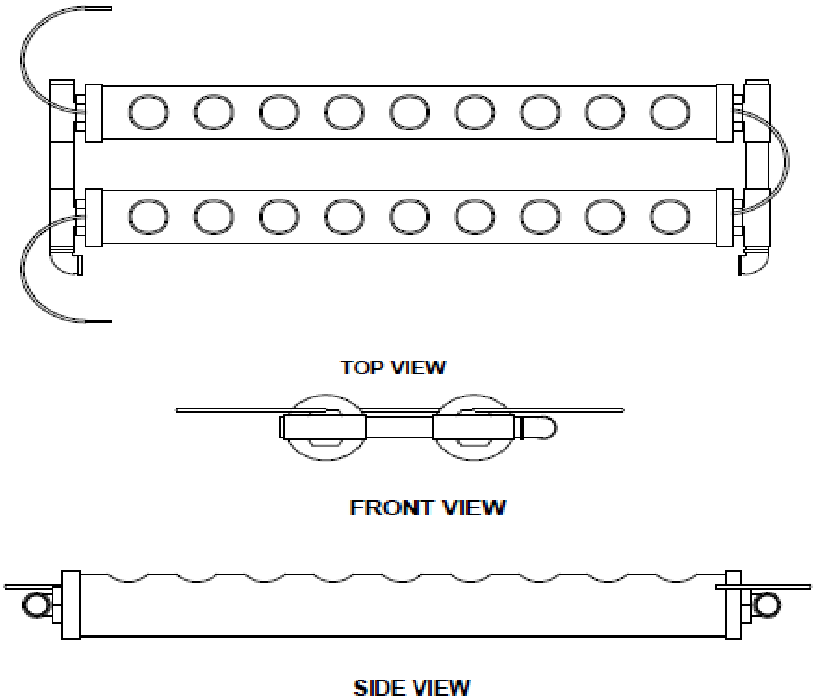

Figure 1. Top, Front, and Side view of the hydroponic frame

III. Results:

With the above-mentioned techniques, the plants will be grown in net pots. Those net pots or containers will be kept in a foam sheet frame on the tray such that the plants can absorb nutrients from the nutrient solution present in the tray or another container placed below that frame. This setup (shown in Figure 1) will be connected to a reservoir that contains nutrient solution, a water pump, and an airstone. That air stone will be connected to the air pump present outside the reservoir. For some plants we need LED grow lights. Now for growing plants, we must ensure the nutrients and pH value of certain plants and need to maintain them to grow those plants.

IV. Conclusion:

In Indian Space Station we cannot grow plants with the help of soil because there is zero gravity. It is cost-effective but also increases productivity rate, we are taking this hydroponic cultivation in the Indian Space Station for astronauts present there because the packed food they eat may cause severe health issues when they return to Earth. Using this hydroponic cultivation method the plants grown are more hygienic compared to the packed food they carry from Earth. They can grow required crops according to their needs and under their supervision anytime.

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