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Solar-powered hydroponic radish garden - A senior student project

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Abstract. The global population has increased by 25.8% in the last 20 years and currently stands at over 8 billion. New and innovative techniques will be required to continue feeding the world and avoid malnutrition. Hydroponic and vertical farming are promising tools for achieving this goal. These tools allow for food production in a controlled environment without using soil. Although currently more expensive than conventional farming, they offer food production in a well-controlled environment. The plants are continuously monitored and adjustments in temperature, relative humidity, pH and nutrient composition are made as needed. Other benefits include relative immunity to weather conditions, pests and water contamination. Additionally, water consumption is minimized. This article reports the results of a ***senior-student project***, the objectives of which were to design, build and test a small hydroponic system utilizing renewable energy to grow French dressing radishes. The constraints included a minimum yield of 1 kg per m^2 of footprint (in 3 months), fully automatic irrigation pump/fertilization and fully solar/battery powered system. The total cost was limited to USD 250.

Key words. Hydroponic Farming, Hydroponic Radishes, Solar Powered Pump

1. Introduction

In many regions of the world, such as the U.S. Midwest, produce cannot be grown year-round due to cold winters. For centuries, people living through cold winters were forced to preserve food by canning, or sometimes by storing their food in a cold underground cellar. However, today's modern technology and transportation systems allow almost all food items to be available year-round. There are challenges and downfalls to transporting food long distances as this can result in food contamination. Another challenge in modern agriculture is the excessive quantity of fuel used to transport large amounts of food long distances resulting in damage to the environment.

Hydroponics means growing plants without the use of soil (Fig. 1). It has many applications including food production in urban areas, warehouses and also in outer space [1].

Hydroponic growing systems offer many benefits including as much as 95% reduction in water consumption, the ability to grow food year-round and reducing the risk of food contamination by pathogens such as salmonella and listeria. Disadvantages of hydroponic systems include expensive infrastructure and high cost of the energy required to operate the pumps, grow lights and control systems. As such, hydroponic systems are most appropriate for growing expensive crops and herbs such as saffron [2],[3]. They rely heavily on continuous cycling of water within the system and a reliable source of electricity. When using LEDs for a lighting system, a power outage will end the manmade lighting and the flow of water. Because hydroponic plants have small root systems, they are unable to support themselves well and must be watched. Initial startup of hydroponics is much more costly than conventional farming.

Hydroponic food production can be highly profitable in a multitude of ways, including increased yield of crops, control over variables such as air humidity, pH, temperature, light, etc., less water, regional diversity, and fewer toxins. It allows people to grow food in areas where droughts are common and regions in which some crops are difficult to grow.

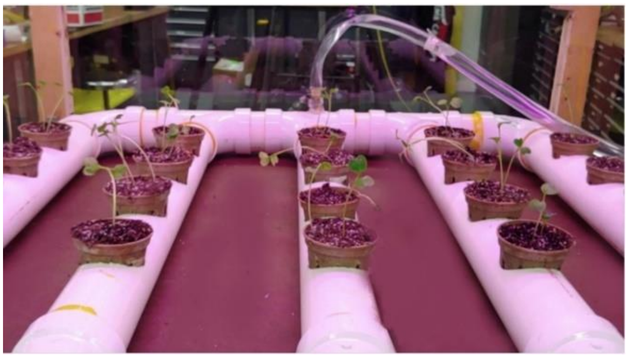

Fig. 1. Close up of a hydroponic system [4]

Hydroponics dates as far back as 2000 years ago as evidenced in the hanging gardens of Babylon, in Egyptian hieroglyphics, as well as in ancient civilizations along the Nile River. According to [5], "… and the Aztecs employed hydroponics in their floating gardens in Mexico, planting crops on rafts floating on the surface of Lake Tenochtitlan. Farmers trained the roots to trail beneath the raft, accessing lake nutrients that would otherwise be inaccessible."

After the *Industrial Revolution*, development of hydroponics occurred between 1925 and 1935. Unfortunately, during this time period hydroponics was not widely accepted due to the high cost of resources and labor. Hydroponics made another appearance after *World War II* primarily to grow cucumbers and tomatoes. The idea was once again rejected due to system flaws and lack of technology. In the 1960s, plastics were just becoming popular. They were introduced into hydroponics. Plastic was used to line the growing beds instead of concrete. The rise in oil prices in 1973 once again diminished the interest in hydroponics. Escalating oil prices substantially increased the cost of heating and cooling. Interest in hydroponics came back almost 20 years after the rise in oil prices. In contemporary times, advancements in technology have made hydroponics more beneficial and space efficient.

Modern hydroponics started with a man named William Frederick Gericke, who deduced that plants did not require soil to grow, but rather nutrients and water. He coined the term hydroponics within modern society and proved his own hypothesis by growing 25-foot-high tomato vines using a hydroponic system [6].

2. Initial Design

Figure 2 depicts the initial design. It was simple enough to build using many components already available at the University.

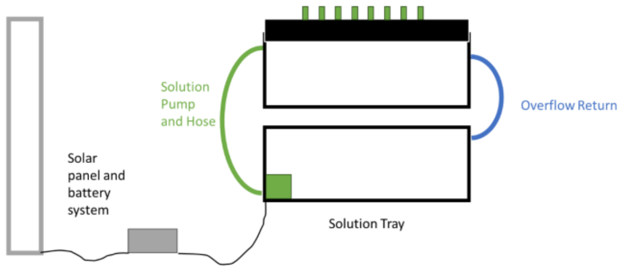

Fig. 2. Sketch of the initial design

The main idea behind this initial design was to use a simple, two-tank, gravity-driven system. Because of its simplicity, this design would have been easy to construct and thus allow the team plenty of time to grow the radishes. Also, with a simple electrical circuit, this design would have presented very few, if any, electrical challenges. Finally, without much height to move water around, the pump demand would be low, reducing energy consumption.

While simple, this design presented many challenges to the overall goal of the project. This design would not provide much space to grow the desired quantity of radishes. Additionally, this design would have required a very large volume of water, which would not only be heavy, but hard to maintain if this system were to be utilized for household usage. Similarly, this system would take up quite a bit of space, which would be contrary to one of the design constraints of the project. All these issues were addressed by the final design.

3. Finalized Design

To overcome the challenges presented by the initial design, an alternative design was developed to utilize gravity, take up less space, and have more space to grow the radishes more effectively.

As seen in Fig. 3, the final design was composed of two side-by-side PVC pipes at alternating angles. The group constructed three pairs of these pipes to maximize grow space and provide a waterfall effect between the three rows (Fig. 4).

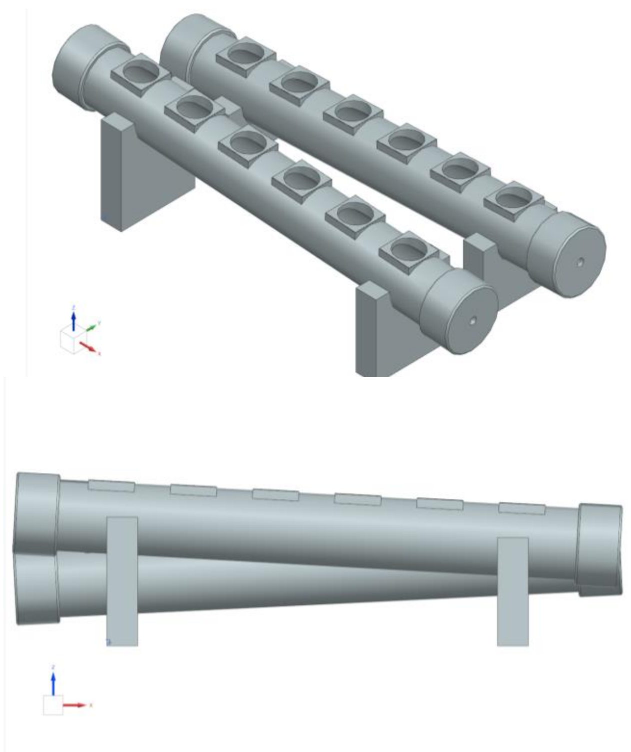

Fig. 3. CAE model of the final design

Fig. 4. The assembled hydroponic system

In addition to the six PVC pipes, the system included a solar panel, a battery, and a pump, all managed by a basic battery control module (Fig. 5). Keeping the electrical system simple helped reduce build time and the possibility of electrical issues. Additionally, this system took up minimal space, only requiring an area of about 1 m^2 to grow up to 36 radishes. Finally, by using this tumbling tube system, the required volume of water in the system was greatly reduced.

Fig. 5. Battery control module (covered to prevent rain damage)

4. Battery and Pump Selection

Due to budgetary constraints, it was decided to use the solar panel, the battery, the timer, fertilizer and one of the two pumps already available at the University. Ensuring the available pump and battery were strong enough to support the system was a vital step in the process. Calculations were performed to determine what size battery was required depending on pump selection, and whether the design was to include grow lights (Table I).

Table I. - Battery Calculations

	Pump No. 1	Pump No. 2	Grow Lights
A	2	1.2	4.167
V	12	12	12
W	24	14.4	50
Wh (12 hours)	288	172.8	600
Ah (12 hours)	24	14.4	50
Wh (16 hours)	384	230.4	800
Ah (16 hours)	32	19.2	66.67
Wh (24 hours)	576	345.6	1200
Ah (24 hours)	48	28.8	100

During the early stages of design and construction, Pump No. 2 was selected, due to its low electrical demand and its ability to pump water to the height needed. Similarly, grow lights were omitted from the design, as even low-demand lights would draw too much energy from the available batteries. In the end, a 30Ah battery was selected. The reason behind this was to be able to run the system continuously, and always have water and nutrients circulating, regardless of weather conditions and solar irradiance.

After the initial testing of the battery, the solar panel, and the pump, it was found that Pump No. 2 was dysfunctional, thus the group had to switch to Pump No. 1. Limited by the size of the battery, the system operation hours changed from round the clock, to only 12 hours of pumping overnight.

After this minor setback, the pump calculations had to be redone to ensure Pump No. 1 was strong enough to provide flow to the system (Table II).

Table II. – System Specifications

Variable	**Value**	**Units**
Volumetric Flow Rate	0.473	liters/s
System Volume	20.85	liters
System Refresh	44.1	seconds
Water Velocity	0.94	m/s

It was determined that even if this pump had an efficiency of only 50%, it would still have more than enough power to always provide the system with flow. In fact, this pump proved to be too powerful, which led to the addition of a manual flow control ball valve. This addition is seen as an improvement, as this will allow the users to completely stop the flow of water in case of repairs, cleaning, or replacing the plants.

5. Seed Germination and Fertilization

Germination of the seeds was initiated by placing them on a damp cloth for a week. Once the seeds germinated and were showing signs of growth, they were transferred into grow cups filled with soil. The soil was used to hold the plants in place. Planting multiple seeds in a single cup is a strategy to increase the chances of growing at least one seedling successfully. Planting in damp, compacted soil ensures that the seedlings have access to moisture right from the start. The plant roots then grow inside water containing fertilizer, arguably the most important part of the process.

The hydroponic fertilizer used contained ammonia, nitrate, phosphate, soluble potash and magnesium. It provided the radish seedlings with the nutrients they needed to grow. As the seeds and plants developed, the volume of grow food was adjusted according to the instructions on the bottle. With the calculated system water volume, a total of 1.5 teaspoons of the fertilizer was used initially.

It should be noted that many media are available to hold the plants in place (instead of soil). Examples are Oasis Cubes, Coconut Fiber, Perlite, Vermiculite, Rockwool and Soilless Mix [7].

6. Results and Conclusions

Figures 6-8 exhibit the system at various stages of development. Overall, even though this project did not meet the initial production goal of 1 kg of radishes, all other design constraints were met. The system took up less than 1 m^2 (10 ft^2) of floor space while producing up to 36 individual plants. The system is gravity-driven and self-regulating, allowing users to put in very little time and nearly no money while reaping the benefits of fresh homegrown produce. Thanks mainly to the solar panel and the battery, this system will have net zero emissions and electricity costs. Also, this system was produced inexpensively, quickly, and easily. Given some extra time, the system could have been even more aesthetically pleasing, with a compartment to hide all the electronics and with the pipes secured to the structure. Overall, this 11-week project was a success, but can still be improved in the future.

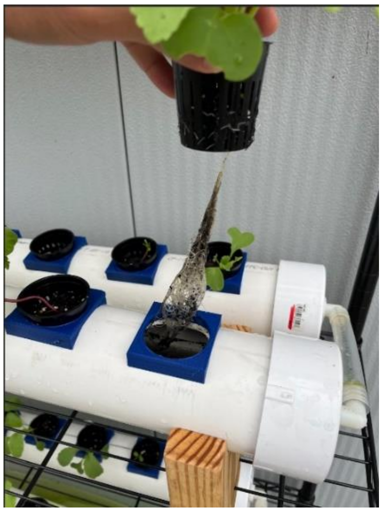

Fig. 6. Plant roots immersed in water

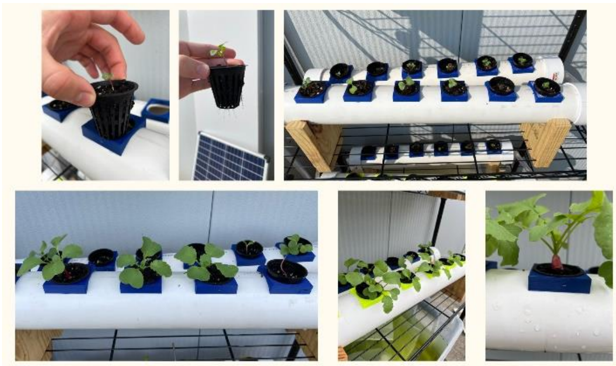

Fig. 7. Collage showing various stages of the project

Fig. 8. French dressing radishes growing

7. Challenges and Suggested Solutions

A multitude of challenges were encountered during the design and construction of this hydroponic system. Some of these were predicted and minimized, and others were unforeseen but repairable. In order of appearance, the challenges were as follows:

First, the original pump selected for the hydroponic system was damaged or dysfunctional. This led to a minor redesign of the system, with different-sized hoses and flow rates, but overall, this obstacle was minor and easily overcome. It even led to a modest improvement in functionality with the addition of the manual flow control valve.

Secondly, a few of the radish sprouts were eaten or damaged by insects, leading to a reduction in potential yield (Fig. 9). This problem was overlooked, and thus a solution had to be found quickly. Pesticides and bug spray were considered, but with the risk of potential contamination of the water, this solution was avoided. If another group were to do this project, protective nets would be recommended to keep pests away while still allowing for plant growth.

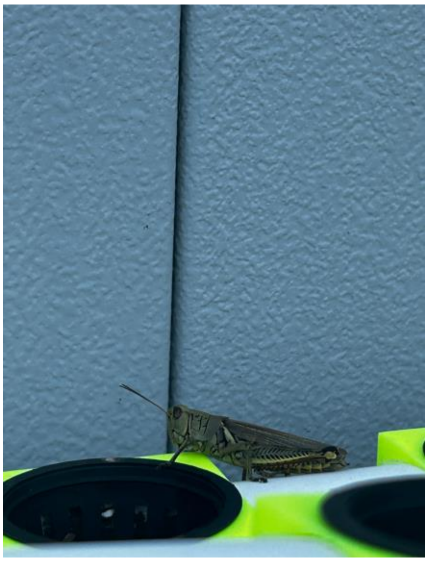

Fig. 9. Grasshoppers like this one damaged the plants

Third, unexpected rain caused some damage to the battery controller since it was not covered or protected. A simple fix to this problem was to cover the battery controller with a plastic bag and tape it shut (Fig. 5), but in future projects, a more aesthetically pleasing way to weatherproof the electrical components of the system should be pursued, such as constructing a storage area for the battery and controller. Due to the short duration of this project, this was not practical.

Finally, the design of this system led to occasional clogging of the pipes. As water circulates through the system, it picks up loose dirt which accumulates in the pipes, eventually causing blockage. The design proposed in this project does not prevent this very well. Future projects should consider using a different kind of grow cup, a different substance for holding the plants in the cups, or a filtration system. Examples of plant holding media include Oasis Cubes, Coconut Fiber, Perlite, Vermiculite, Rockwool, and Soilless Mix.

8. Concluding Remarks

An important application of hydroponics is growing plants in space for food. Frequent resupply missions are required to transport food, water, and oxygen to the *International Space Station* (ISS). The cost to send food to the ISS has been estimated at about $10,000 a pound [1].

Growing food in space using soil is virtually unthinkable but highly viable with hydroponics. The concept can be applied to advance human exploration and building communities on other extraterrestrial bodies. Remaining in space for an extended period of time requires a maintainable and sustained food supply.

Having garden-fresh food in space is favorable for several reasons. In the first place, growing food will allow for ongoing human habitation almost anywhere with the facilities to grow crops. This will allow humankind to scout further and further away from the Earth. Growing plants will also have positive psychological and therapeutic benefits on humans [8]-[10]. Past studies indicate that the modest act of taking care of plants is a stress diminishing engagement for humans in a stressful space environment.

These benefits can be applied to both space exploration and colonies on other planets, moons, or asteroids. In the absence of vertical farming and hydroponics, it will be nearly impossible to set up a human colony on a planet like Mars or even the moon as it would necessitate continual and timely resupply missions without which the colonists would starve.

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References

[1] J. Hirsch, "Space Farming: The Final Frontier," modern farmer, 10 Sep. 2013, Space Farming: The Final Frontier - Modern Farmer

[2] F. F. Souret and P. J. Weathers, "The Growth of Saffron (Crocus sativus L.) in Aeroponics and Hydroponics," Journal of Herbs, Spices & Medicinal Plants, Volume 7, 2000 – Issue 3, The Growth of Saffron (Crocus sativus L.) in Aeroponics and Hydroponics: Journal of Herbs, Spices & Medicinal Plants: Vol 7, No 3 (tandfonline.com)

[3] M. Kordestani, "Hydroponic Saffron Cultivation and the Effects of Soil Salinity, " 4 Nov. 2019, Hydroponic Saffron Cultivation and the Effects of Soil Salinity | by Milan Kordestani | Medium

[4] J. Miller, Z. Spinning, O. Swain, M. Sanchez, and A. Pourmovahed (2021), "*Urban Hydroponic Herb and Spice Garden*", In: da Costa Sanches Galvão J.R. et al. (eds) Proceedings of the 1st International Conference on Water Energy Food and Sustainability (ICoWEFS 2021). ICoWEFS 2021. Springer, Cham. https://doi.org/10.1007/978-3-030-75315-3_14

[5] O. Robbins, "Hydroponics: How It Works, Benefits and Drawbacks, & How to Get Started," FOOD REVOLUTION NETWORK, February 24, 2021, Hydroponics: How It Works, Benefits & How to Get Started (foodrevolution.org)

[6] K. Espiritu, "*History of Hydroponics: When Was Hydroponics Invented?," 18 July 2018,* https://www.epicgardening.com/history-of-hydroponics/#SnippetTab

[7] B. Ingham, "The Complete Guide To The Best Hydroponic Growing Medium," HYDROPONICS, BIGGER GARDEN, 26 September 2023, Hydroponic Growing Medium Complete Guide | 18 Types + Best (biggergarden.com)

[8] Nasa astronauts take first bites of lettuce grown in space: 'Tastes like arugula', The Guardian, Nasa astronauts take first bites of lettuce grown in space: 'Tastes like arugula' | Space | The Guardian.

[9] C. Huston, "Growing Plants in Space," NASA, Dec. 8, 2023, Growing Plants in Space - NASA

[10] Researchers are learning to grow plants in orbit to prepare us for living on other planets, NASA, July 22, 2022, So You Want to Be a Space Farmer… - NASA