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Vertical Farming (Hydroponics)

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Abstract- In the current times, conventional farming which is the most widely used type of farming has been affected by several problems such as decrease in the availability of space due to the increasing population, wastage of water, destruction of crops due to insects, rains, etc. Furthermore, in the future where the population is expected to grow further, these problems in farming can be disastrous as it can decrease the availability of food and can lead to the starvation of a big part of the population. Hydroponics which is another method of farming can be a solution to most of the problems associated with conventional farming. In this type of farming, crops are grown without the requirement of soil, instead it utilizes a growing medium and water is directly supplied to the roots of the plants. Further fertilizers are dissolved in the water itself. This type of farming can save a lot of space as the plants are grown in vertical slots and they can be stacked upon each other and water requirement is also very low for this type of farming as most of the water is recycled. In this paper, we are going to discuss the various factors which affect the growth rate of the plants in vertical farming. The plants we have taken are jalapeno plants. The trail period is of 7 weeks where we have compared different factors affecting the growth rate of the plants.

Index Terms- conventional, food, hydroponics, soil, vertical, jalapeno

I. INTRODUCTION

Agricultural production is experiencing increased pressure to generate larger yields as the global population is rising and demand for food is increasing (1). In order to feed this growing population, there is a need for and increased and sustainable food production. According to the United Nations World Food Programme, nearly 1 billion people worldwide are undernourished (FAO, 2012). About 42% of these chronically hungry people live in India and China, two of the world's most populous nations (2,3). By 2050, the population is expected to reach 8.9 billion and world has to produce 50% more food, thereby requiring an additional arable land that is simply not available. This decline is forecasted to continue due to the effects of climate change, the increasing geographic extent of drylands, the reduction in fresh water supply, and population growth. It is projected that to feed the global population by 2050, we require 70 percent increase in global food production with food production from developing countries be doubled (4,5,6). With an uptrend in climate extremes and global warming, farmers are increasingly adopting farming in a controlled environment where environmental conditions including light and temperature can be regulated (7). In light of the above, the need for innovation in land-use efficiency for crop production is therefore increasingly important (8).

Vertical farming is one of the crop production strategies that falls under the term-controlled environment agriculture. Vertical farming is the practise of using less water and no soil to grow crops in vertically stacked layers or integrated into other structures (such as a skyscraper or old warehouse). Vertical farming could enable food production in an efficient and sustainable manner, save water and energy, enhance the economy, reduce pollution, provide new employment opportunities, restore ecosystems, and provide access to healthy food (9,10,11). Similar with vertical greenery, vertical farming can benefit urban heat island mitigation, thermal insulation and shade, and noise pollution reduction. Vertical farming has both advantages and disadvantages. One advantage is that neither soil nor sunlight is needed in vertical farming; thus, soil-borne pests and most abiotic stresses such as environmental effects resulting from weather conditions or day lengths do not interfere with the system. Approaches to vertical farming are numerous and varied, including green walls where produce is grown on a vertical or inclined surface and growth around vertically orientated cylinders. However, the most commonly used approach comprises stacked horizontal beds of soil-based or soil-free cultivation (12,13,14). Crop production in VFS relies on controlled environments: light (intensity, spectrum, profile, and daylength), carbon dioxide (CO_2) concentration, temperature, air humidity, air flow, plant density, and water and nutrient availability are tightly regulated (15). Vertical farming potentially contributes to future food production, offering a technologically advanced production system. However, the high energy demand, capital costs, and limitation in crop variety to be grown are major challenges to achieving the triple pillars (planter, people, and profit) of sustainability (16).

In vertical farms, plants grow in soilless cultivation systems such as hydroponic (roots are immersed in multiple substrates, i.e., perlite, rockwool enriched water with nutrient solution), aeroponic (soilless air/mist solution) or even aquaponic (co-cultivation of fish and hydroponic plants) systems that allow stacking multiple layers or columns of plants horizontally or vertically (17,18,19). Since vertical farming is experimented within a closed and controlled environment, sunlight as a source of light for carrying out photosynthesis is replaced by artificial lights with different spectra and intensities. In such a case, LED lights are more effective with high energy use efficiency and durability than traditional light sources like fluorescent lamps (20,21,22). One of the most widely used hydroponics technique is nutrient film technique (NFT), in which roots partially hang in a sloped channel through which a thin layer of nutrient solution is pumped (23). This hydroponic system requires special attention to several parameters such as the water temperature, water level, acidity (pH), and the concentration of the nutrient (EC/PPM) (24, 25). For our study, we have grown jalapeno plants using NFT technique. Our aim is to evaluate various factors such as light duration, nutrient concentration, etc and optimize them to obtain the best set of parameters.

II. MATERIALS AND METHODS

1. Materials

Hydroponic Solution

The hydroponic solution refers to the nutrient-rich water mixture used to provide essential elements and minerals directly to plant roots.

The hydroponic solution contains a carefully balanced mix of essential nutrients required for plant growth. These nutrients include macronutrients such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulphur (S)

Submersible Water Pump

Submersible water pumps are workhorses designed to operate entirely underwater. They are ideal for pumping water from wells, cisterns, or flooded basements. They come in various horsepower ratings to handle different depths and pumping capacities. Submersible pumps are typically energy-efficient and require minimal maintenance.

Drip System: 16 mm pipe and 4mm nozzles.

Drip irrigation is a water-saving system that delivers water directly to plant roots. It uses a network of tubes with emitters that slowly release water exactly where it's needed, minimizing evaporation and runoff, making it ideal for arid regions and water conservation efforts. By providing precise amounts of water, it promotes healthier plant growth and reduces weed growth, as water is only delivered to desired areas.

50L - Water Tank Reservoir

This acts as our main water storage tank- In hydroponics, a 50L water tank reservoir serves as the primary water storage, ensuring a consistent and ample supply of nutrient-rich water to the plants. This reservoir size is sufficient to support a moderate-scale hydroponic system, maintaining optimal water levels and stability for plant growth

Coco fibre and Coco Pellets

Coco fibre and coco pellets are popular growing mediums in hydroponics due to their excellent water retention, aeration, and sustainability. Both materials are pH-neutral and free from pathogens, making them ideal for hydroponic systems where precise control of nutrient levels and water is essential. Their use supports sustainable agriculture by repurposing coconut waste into valuable growing mediums.

Grow Lights and LED's

LEDs, or light-emitting diodes, are solid-state lighting devices that are very energy-efficient and have a long lifespan. They are becoming increasingly popular for general lighting applications due to their many advantages over traditional incandescent bulbs. LEDs also have a lower environmental impact due to their reduced energy usage and longer replacement intervals, contributing to less waste. Regular advancements in LED technology continue to enhance their performance and efficiency. Channels 1 and 4 are fitted with tube lights that emit a combination of red and blue spectrum light. This specific light spectrum is tailored to promote robust photosynthesis and vigorous plant growth. The light distribution for these channels is as follows: Blue light (400-500nm) constitutes 14.0% of the spectrum, which is essential for vegetative growth and strong stem development. The Green light (500-600nm) comprises 34.0%, aiding in overall light penetration and supporting various plant functions. Red light (600-700nm) makes up 43.0% of the spectrum, crucial for flowering and fruiting stages. Channels 2 and 3 utilize full-spectrum lights designed to mimic natural sunlight, providing a balanced range of wavelengths that support all growth stages of the jalapeno plants. The spectral distribution for these lights includes 5.0% Blue light (400-500nm), promoting chlorophyll synthesis and leaf development. This strategic deployment of lighting systems ensures that the jalapeno plants receive tailored light conditions conducive to their specific growth requirements at different stages, maximizing yield and quality in the hydroponic environment.

Metal Body and Movable casing for whole System

In hydroponics systems, the use of a metal body and movable casing provides durability, mobility, and protection for the entire setup. A metal body ensures structural integrity and longevity, resisting corrosion and wear in humid

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environments. The movable casing allows for easy relocation and repositioning of the system to optimize light exposure and facilitate maintenance. Additionally, the casing can protect sensitive components from environmental factors and physical damage, enhancing the overall efficiency and reliability of the hydroponic operation.

Nutrient Film Technique channels made up of PVC pipes
We have used 4 such channels in our experiment- The Vertical Nutrient Film Technique (NFT) system represents a sophisticated approach to hydroponic cultivation, specifically tailored to maximize space efficiency and plant growth. At its core, this system comprises vertically oriented PVC channels or tubes with slot, carefully designed to support plants while facilitating the continuous flow of nutrient-rich water.

Timer
In vertical farming, particularly with hydroponic systems, timers play a crucial role in automating and optimizing various processes essential for plant growth. They regulate the lighting schedule to mimic natural sunlight cycles, ensuring plants receive adequate light for photosynthesis. Timers also control irrigation systems, precisely managing the delivery of nutrient-rich water to plant roots at regular intervals, which prevents over-watering or under-watering. Additionally, they can be used to manage the activation of pumps, fans, and other equipment, maintaining ideal environmental conditions and enhancing overall efficiency and productivity in the vertical farming setup.

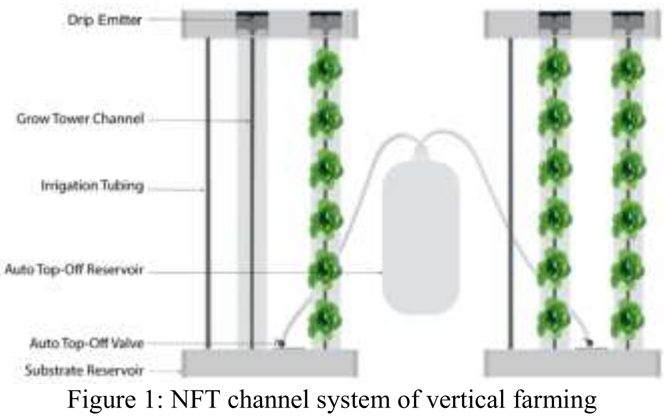

Figure 1: NFT channel system of vertical farming

2. Design

The process begins with the preparation of a nutrient solution, meticulously calibrated to provide plants with essential minerals and elements necessary for their growth. A submersible pump then propels this solution from a reservoir to the top of the vertical channels. From there, the solution cascades down the channels, forming a thin film along the inner surface. This nutrient film bathes the roots of the plants, ensuring they receive a constant supply of water, oxygen, and nutrients. As the solution flows downwards, the plants' roots absorb the necessary substances, promoting healthy growth and development. Excess solution collects at the base of the channels before being recirculated back to the reservoir, minimizing waste and ensuring resource efficiency. This system's vertical design allows for high plant density in limited spaces, making it particularly suitable for urban agriculture and indoor farming. Additionally, its ability to provide plants with a continuous supply of nutrients fosters optimal conditions for robust root development and accelerated growth. However, to maintain optimal performance, regular monitoring and maintenance are essential to prevent clogging and ensure proper nutrient distribution. Overall, Vertical NFT represents a sophisticated and efficient approach to hydroponic cultivation, offering a viable solution for maximizing productivity in constrained environments.

Drip Irrigation System: It mainly consists of a reservoir, pump, tubing, drip emitter(nozzles) and a timer. Recirculating drip systems are by far the most commonly used. The recirculating drip systems are like it sounds, it simply refers to reusing or recycling the used nutrient solution after it has wet the roots back to the reservoir where it can be recirculated through the system, and used over and over again. Recirculating systems are also known as recovery systems because it refers to recovering the used nutrient solution so it can be recirculated through the system again. This greatly reduces water need.

The system uses individual pots for plants and the water from the reservoir is connected to the plants by a network of tubing. There are mainly two ways to apply pressure to the water supply. And it can be a regular water pump or a gravity-based system. Each plant gets at least one dedicated drip emitter and each emitter has mechanisms that allow you to control the flow of water. This adds to the overall versatility of the system; you can set different flow levels for different plants. The flow to the plants has to be regulated in a drip system and the growing media needs to be given time to breathe in between flows. If left uncontrolled, a drip will flood the plants and eventually drown them. Thus, all drip systems use some kind of timer system to regulate the flow of water and nutrients to the plants. In typical situations, the pump is operated many times a day to send water to the plants. Such a drip system requires considerable planning and effort in the initial stage. But once the drip lines and carefully installed, the drip system can run with minimal assistance. Then, these systems can be designed to have a high degree of automation.
Coco pellets- Coco pellets, made from compressed coconut coir, are popular in gardening and hydroponics due to their excellent water retention, aeration, and natural disease resistance. When hydrated, they expand significantly, providing a loose and airy medium ideal for seed starting, hydroponics, and container gardening. Coco pellets have a neutral pH, support healthy root growth, and are an eco-

friendly alternative to peat moss. They can also be mixed with garden soil to improve its structure and nutrient-holding capacity. Ensure they are pre-washed to remove excess salts and store them in a dry place to prevent premature expansion.
Coco fibre- Coco fibre, derived from coconut husks, is a sustainable, eco-friendly material used in horticulture and agriculture for its excellent water retention, aeration, and durability. With a neutral pH, it supports healthy root development and is resistant to soil-borne diseases. Applications include use as a growing medium, soil amendment, and in erosion control products. It is also employed in industrial products like ropes and mats. To use, hydrate the coir fibre before mixing with soil or using in hydroponic systems. Ensure high-quality, pre-washed fibre to avoid excess salts, and store it in a dry place to maintain quality.

Drip Irrigation System: It mainly consists of a reservoir, pump, tubing, drip emitter(nozzles) and a timer.recirculating drip systems are by far the most commonly used. The recirculating drip systems are like it sounds, it simply refers to reusing or cycling the used nutrient solution after it has wet the roots back to the reservoir where it can be recirculated through the system, and used over and over again. The system uses individual pots for plants and the water from the reservoir is connected to the plants by a network of tubing. Each plant gets at least one dedicated drip emitter and each emitter has mechanisms that allow you to control the flow of water. This adds to the overall versatility of the system; you can set different flow levels for different plants. The flow to the plants has to be regulated in a drip system and the growing media needs to be given time to breathe in between flows. Then, all drip systems use some kind of timer system to regulate the flow of water and nutrients to the plants. Such a drip system requires considerable planning and effort in the initial stage. Once the drip system is successfully installed we can add the fertilizers to the water reservoir, thus creating the nutrient solution.

Figure 2: Sprouting Stage

Figure 3: NFT channels with plants

Figure 4: Overall Hydroponic System

III. RESULTS AND DISCUSSIONS

So, for our project, the main experimentation we have done is changing certain parameters and then observing their effect on the growth rate of the plants. By this way, we can obtain the best optimized conditions for the plants.

Effect of Positioning of Plants
Now, we can understand 2 main conclusions in our project. First one is that the growth rate increases in each channel as we go downwards towards the centre of the channel and the growth rate of the plants of the central channels which are the second and third channels is more than the growth of the first and last channels. This is because light is maximum at the centre of each channel and the central channels receive white light whereas the outer channel only receive blue-red light. When plants receive blue-red light in the initial stages, it is effective in increasing the growth rate of the plants. But when the plants reach a certain stage, they need to get white light in order to get the whole light spectrum for better yield and growth rate. The difference in the growth rates can be seen in the graph below.

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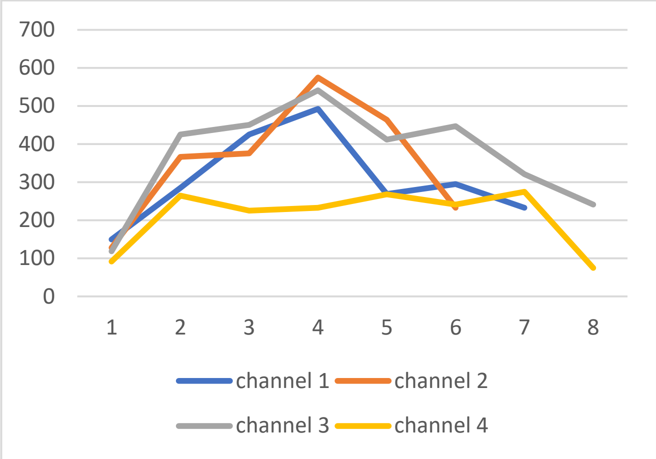

Figure 5: Comparison of growth rate of plants in each channel

On the y-axis, we have the growth rate of the plant in percentage which was obtained by comparing the height of the final plants with the height of the plants when they we implanted in the channels. As you can see, the plants in the middle channels (plants 3,4,5) have higher growth rate and channels 2 and 3 have better growth rate than channel 1 and 2. Comparison of plants grown in pots vs plants grown hydroponically

The second conclusion we have come to is that the growth of plants grown hydroponically is better than the growth of plants grown in soil. To prove this, we had grown some plants in pots and then, we have created a graph that compares the growth rate of the hydroponic system and the potted plants.

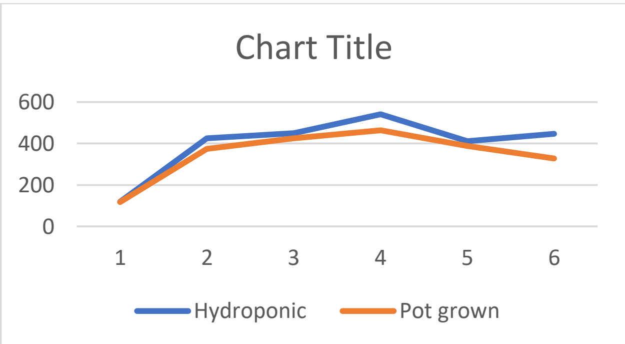

Figure 6: Comparison of plants grown in pots and plants grown hydroponically

In the above graph, it can be clearly seen that the plants grown hydroponically have better growth rate than the plants grown in soil.

Effect of Fertilizers

So, we have carried out our project in a time span of 7 weeks. In each week, we have done a parameter change. So, first for a week, we did not make any changes in the parameters and did not add fertilizers to get a base growth rate and we call this week as week 0. Then, in the first week, we add the base amount of fertilizers which we obtained through research.

Table 1 Actual Nutrient Requirement.

MACRO-Nutrients	Total
Ca(No3)2	1666
KH2PO4	219
K2SO4	558
MgSO4	510
MICRO-Nutrients	Total-Supplied
Fe-EDTA	16
MnSo4.H2O	1.54
H3BO3	1.71
ZnSO4.7H2O	0.44
CuSO4.5H2O	0.2
(NH4)6Mo7O24.4H2O	0.09
NaCl	0.16

Then, for the second week, we increase the fertilizer by an experimental amount.

Table 2 Experimental Nutrient Requirement.

MACRO-Nutrients	Total
Ca(No3)2	1740
KH2PO4	260
K2SO4	600
MgSO4	550
MICRO-Nutrients	Total-Supplied
Fe-EDTA	18
MnSo4.H2O	1.7
H3BO3	1.8
ZnSO4.7H2O	0.55
CuSO4.5H2O	0.3
(NH4)6Mo7O24.4H2O	1
NaCl	0.18

Then, we obtained a graph and the difference in the growth rate of both weeks can be understood through the graph.

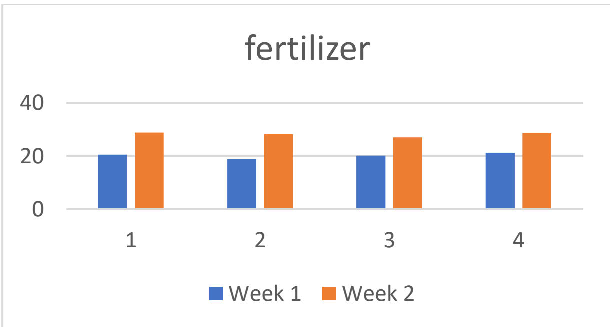

Figure 7: Growth chart for first constraint.

In the above graph, the blue bars (on the left) represent the average growth rate of the plants in each channel in the first week and the red bars (on the right) represent the average growth rate of the plants in the second week. As we can see, in the second week, when surplus fertilizer is added, the growth rate increases. This happens because, when we add surplus amount of fertilizer, we compensate for the plant growth that happens throughout the week which we can't do if we only add a base fertilizer amount based on the previous plant conditions.

Effect of Light and Water Duration

So, for weeks 3, 4, 5 we have changed the parameters of light and water. So, for week 3, we have kept the light and water parameter constant. For week 4, we increased the light time from 8 hrs to 12 hrs while keeping the water time constant. And for week 5, we kept the light time constant at 12 hrs and changed the water time from a constant 8 hrs per day to 4 hrs per 12 hrs. We then obtained the following graph.

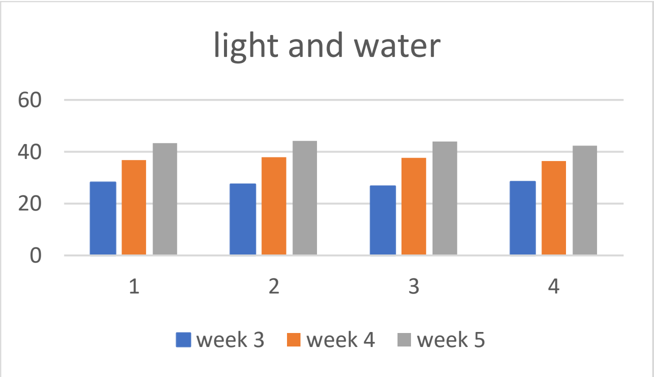

Figure 8: Growth chart for second constraint.

As you can see in week 4, when we increased the light time, the growth rate increased and in week 5, when we changed the water time, the growth rate increased further more. The reason this happens is generally plants receive from nature sunlight for about 12 hrs which is adequate for the plants to carry out photosynthesis and therefore produce enough food. So, when we increase the light time to 12 hrs, we therefore give plants more light which therefore increases their efficiency as we mimic nature. Also, when we give plants water continuously water for 8 hrs, because water continuously falls on the roots for such a long time, there develops a higher chance of root rot and also, the roots receive lesser oxygen from the air but when we water the plants in 2 batches, we give the plants enough time to dry and absorb more oxygen.

Effect of Humidity

In week 6, due to rainfall, the average temperature and humidity fell due to which there was a small effect on the growth rate which can be seen in the graph below.

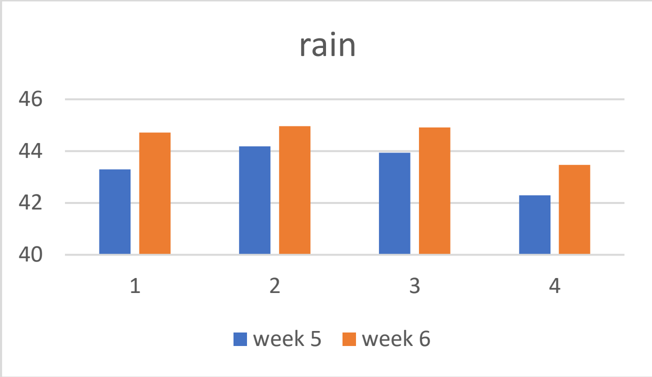

Figure 9: Growth chart for third constraint.

As we can see, the difference in the growth rates is very small. And then, in week 7, we used the above parameters to obtain the most optimized conditions and then obtained the growth rate and then created a graph of comparison of growth rate of week 7 and week 0.

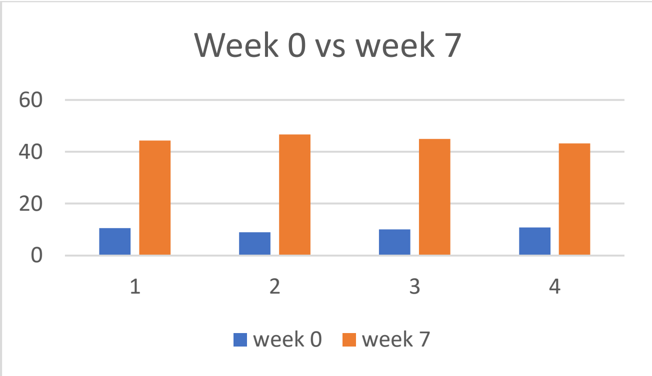

Figure 10: Growth chart for week 0 vs week 7.

As we can see, after optimization, the growth rate obtained is much higher than the original growth rate.

Through our studies, we can conclude that the most important parameters are light exposure and humidity. While water and fertilizer factors are important, those only change the growth rate to a certain limit which is small (26,27). Also, the growth rate only increases to a certain limit. When the plant reaches a certain height, its growth rate decreases regardless of changing these parameters.

Helpful Hints

Equations

- Growth rate percent = (Final length – initial length)/initial length * 100
- Average growth rate = sum of growth rates/number of plants

V. CONCLUSION

Hydroponic farming offers a sustainable, efficient, and versatile solution to modern agricultural challenges. With its ability to grow crops in urban environments, reduce water usage, and increase food security, hydroponics represents a promising future for agriculture. Continued innovation and adoption of hydroponic techniques hold the potential to revolutionize the way we produce food, ensuring a healthier, more resilient food system for generations to come. It maximizes yield in minimal space and allows for year-round production of healthy food. With advancements in automation and technology, hydroponics has the potential to revolutionize food security in a sustainable way. However, continued research and development, as well as addressing economic considerations, are crucial for the widespread adoption and success of vertical farming practices.

Disclosure Statement
No potential conflict of interest was reported by the authors.

REFERENCES

1. https://www.tandfonline.com/doi/abs/10.1080/14620316.2019.1574214
2. https://sciendo.com/article/10.1515/jlecol-2017-0016
3. https://d1wqtxts1xzle7.cloudfront.net/33254643/JAS-V2N1-2014-libre.pdf?1395193758=&response-content-disposition=inline%3B+filename%3DJAS_Vol_2_No_1_March_2014_published.pdf&Expires=1728979088&Signature=MS6wvvcT135KXZP~4VR1ACNuG75H0n~G5~Ujd0PbsJ0a4IBnPUORJlSPiA38qbJZETWDVvyj1up-O468v~UmKc5czmplXUO6TBzCvCMIQ~jDS0YxgVBBJwdIUy8PbX7eux4ihz4OPIDh3BFN~Xgl7w2s~fkzXB0IhFtPUhEM-lfzBtIm4pPVD5FmR3n5ttgLi4DAr-Rb7rQwoK0l2jk8tpO7ZJTDix8t0a~c0gTuUARu0MS3dwIzDaBnf~7m9wpo1XFcXxfBduNTfNVTCGt2QrTYiKFpewBYgiM5jgzy75oWvulbVppNXyUOwA1T-2gSUTtHDjOQfeZN5QSN25pHGQ__&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA#page=43
4. https://www.researchgate.net/profile/Zakir-Amin/publication/358749034_Vertical_farming_The_future_of_agriculture_A_review/links/6213b0604be28e145ca7aab5/Vertical-farming-The-future-of-agriculture-A-review.pdf
5. https://www.tandfonline.com/doi/full/10.1080/15487733.2017.1394054#abstract
6. https://d1wqtxts1xzle7.cloudfront.net/94507962/APAR-01-00023-libre.pdf?1668864472=&response-content-disposition=inline%3B+filename%3DRecent_Trends_in_Agriculture_Vertical_Fa.pdf&Expires=1728980163&Signature=EXFTLrVXuBTiEQg9JsQ6s4HuKiWmM8tdP8FBkOxFB1CwFYsFyuZ3uNBlli8QWS8VRJQAWPKIOmuBF2ojUGrUItZwBXw4rwwhG7MnKeW0us155Up-kGimKdve1ts4M8j7VjdRasMxraoslzJMRc4K5kXpdbZ2E~qm-TrugddgOtB8UMaDIk70TOL0GqDZRLaRNE1d4UUk9Bcm3Pph1CElsCkA2jjfzmfeW~X4Iu9KWOfwGZMtFjkuFxdD9qa51Sj0FvG7jqx8FMwDbL5r0wbH-54W5RGosVI4MHtbQYmwCbRDzMfXMIHQfxxZc6K5sSxrJySYAuDo5LGy9fltZSt6jA__&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA
7. https://www.sciencedirect.com/science/article/pii/S092422442030621X
8. https://onlinelibrary.wiley.com/doi/full/10.1002/fes3.83
9. https://www.mdpi.com/2311-7524/8/4/322
10. https://d1wqtxts1xzle7.cloudfront.net/93240003/VERTICAL_FARMING_AN_OVERVIEW-libre.pdf?1667016630=&response-content-disposition=inline%3B+filename%3DVERTICAL_FARMING_AN_OVERVIEW.pdf&Expires=1728981211&Signature=Ang1ao00Fj2ElVMUJF4faamUCFC5QufxnNe657R3SLxpC0HWungjD-MOprlqe5JXh7S3hl3gztCm91jibHQA72DxEaVVSM96GCdopzhu4PrQt5qUShG-4MdILFwGR~XGeqYmxiU-mTUigk--YXVs2jBYpimbwroBIiH9QtOc-fQparSg0qB~NINsHmAK5yW-xvdrdbRR4t0cMuMVc9SWhHwaHL9gcOjRhQ~LaDYuuXet7pA-saxuQxXPhRfSbYF7F8ZGw7q1yPI7lrwlRnwXq-orINwVmsvtOzi7M7iVKqwoz4bZl7ZWEvK5DQFnTxBNihmqWF7bz9XegaD~6Or~Zg__&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA
11. https://indianfarmer.net/assets/archieves/2020/NOVEMBER%202020.pdf#page=24
12. https://www.sciencedirect.com/science/article/abs/pii/S0378778818327877
13. https://www.mdpi.com/2071-1050/11/15/4052
14. https://onlinelibrary.wiley.com/doi/abs/10.1111/aab.12587
15. https://www.frontiersin.org/journals/science/articles/10.3389/fsci.2024.1411259/full
16. https://www.sciencedirect.com/science/article/abs/pii/S0959652623030810
17. https://www.sciencedirect.com/science/article/pii/S2452263520300021
18. https://www.mdpi.com/2079-9292/10/12/1422
19. https://www.mdpi.com/2071-1050/10/12/4429
20. https://www.scirp.org/html/11-2604257_94632.htm
21. https://www.frontiersin.org/journals/sustainable-food-systems/articles/10.3389/fsufs.2022.849304/full

22. https://www.mdpi.com/2079-9276/10/11/109
23. https://www.sciencedirect.com/science/article/pii/S095965262204015X
24. https://ieeexplore.ieee.org/abstract/document/8089268
25. https://www.mdpi.com/2073-4395/14/9/1932
26. https://www.nature.com/articles/s41598-023-33855-z
27. https://www.sciencedirect.com/science/article/abs/pii/S1618866717304156