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HYDROPONICS FARMING: The technology towards sustainability

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Abstract:

Hydroponic cultivation is rapidly gaining popularity worldwide due to its efficient resource management and ability to produce high-quality food. Traditional soil- based agriculture is increasingly challenged by factors such as urbanization, natural disasters, climate change, and the overuse of chemicals and pesticides, which deplete land fertility. This paper explores Nutrient Film Technique (NFT). It covers their operations, benefits, and limitations, as well as the performance of different crops like tomatoes, cucumbers, peppers, and leafy greens. Additionally, the paper discusses water conservation through hydroponics. Several benefits of this technique are less growing time of crops than conventional growing, round the year production, minimal disease and pest incidence and weeding, spraying, watering etc can be eliminated. Commercially NFT technique has been used throughout the world for successful production of leafy as well as other vegetables with 70 to 90% savings of water.

Key Words: Hydroponics, Vertical Farming, Agriculture, PH Control, Market cost

1. INTRODUCTION

Hydroponic Farming System is a system of growingcrops without soil, often called soilless farming. In the hydroponic system, the liquid nutrient solution is a mixture made up of essential plant nutrients. The plant roots are suspended either in the static liquid solution or in a continuously flowing mixture [1-3]. Unlike the traditional farming system, the hydroponic growing system requires continuous and undivided attention to the crops. In hydroponic farming, plants grow naturally with filled with nutrients and water-rich solutions, under

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optimal positioning of lights and adjusted temperature conditions. Today, 55% of the world's population lives in urban areas, a proportion that is expected to increase to 68% by 2050 and 593mha ofland will need to be turned into agricultural land to fulfil the estimated calorie demands of the worldwidepopulation [4-7]. Furthermore, the occurrence of second- generation problems, such as over-mining of soilnutrients, decline in factor productivity, lowering of groundwater tables and pest build-up, such as weeds, diseases and insects poses serious problems [8-11]. To mitigate these problems, intensification and vertical expansion of agricultural land has been regarded as the only viable options in near future for meeting the rising food demands. Globally, 70% of water usage goes towards agricultural production, largely due to unsustainable irrigation practices (Worldbank.org). In this context, soil-less cultivation i.e., hydroponics,might be inaugurated successfully and considered asan alternative option for growing quality food plants,crops or vegetables (Butler, 2006). One of the most significant advantages of hydroponic farming is the ability to grow crops in near optimal conditions using Controlled Environment Agriculture (CEA) technology. It can be grown anywhere on the world at any time of year, regardless of weather, accessiblecultivable land, or soil quality. Crop production can be kept in a controlled environment, allowing trained personnel to optimize water (saving up to 70% of water), nutrients and light to the plants using advanced climate control technologies. Light inputs are also optimized to ensure maximum plant absorption and yield outputs. Vertical farms expand upwards instead of outwards on a horizontal plane, allowing farmers to grow 3 to 10 times more crops inthe same amount of space as unlike conventional farms [12-15].

2. LITERATURE REVIEW

Santos et al. (2013) the study aimed to use vinasse, a residue from fuel alcohol distillation rich in nutrients, to create a nutrient solution for growing lettuce, watercress, and rocket. After analyzing vinasse's nutrients, a solution with 10% vinasse, similar to Furlani's solution, was developed. Using the Nutrient Film Technique, the study compared this solution with a commercial product for 42 days. Results showed similar growth between both solutions. The vinasse solution led to more lettuce leaves, increased watercress growth, and no significant difference for rocket. This study successfully created a vinasse-based nutrient solution, demonstrating its potential for effective hydroponic cultivation [1].

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Seungjun and Jiyoung (2015) this review covers hydroponic systems, highlighting their advantages over soil-based farming but also addressing challenges like high costs, pathogen risks, and specialized expertise needed. It focuses on using plant growth-promoting rhizobacteria to control pathogens. While acknowledging hydroponics' popularity, it highlights persistent issues like fungal infections, maintenance, and education. The review anticipates ongoing innovations for better hydroponic systems [2].

Suhl et al. (2016) the research explored a double recirculating aquaponic system (DRAPS) that combines fish and plant units to recycle nutrient-rich fish waste water for hydroponic plant growth. Using tilapia and tomatoes, DRAPS showed similar tomato yields to traditional hydroponics, maintaining fruit quality. It improved fertilizer use efficiency by 23.6% and overall water use efficiency. Even with suboptimal fish production, DRAPS ensures good plant growth and fruit yield, offering a promising solution for sustainable and high-yield food production in aquaponics. Continuous nutrient monitoring is crucial for optimal plant growth in DRAPS [3].

Gashgari et al. (2018) this study compares traditional soil-based farming with hydroponic systems using cucumber and Armenian cucumber seeds in a 30-day experiment. Results indicate that while seed type had no significant impact on plant growth, the hydroponic system notably accelerated growth compared to the soil-based system. This finding highlight hydroponics as a potential solution for meeting increasing food demands. Future large-scale experiments considering diverse factors and plant types are needed to validate these findings for broader agricultural application [4].

Chunjie et al. (2019) the study introduced an aquaponics system using immobilized biofilm units for improved water quality and nutrient efficiency in fish and vegetable production. In a 130- day pilot test, the system effectively converted fish waste into suitable nutrients for plant growth, maintaining low pollutant levels. Aquatic plants and biofilm units efficiently removed nitrogen compounds and organic carbon, showing promise for sustainable aquaponics production [5].

Caputo et al. (2020) the study examines urban farmers' adoption of soil-less methods like hydroponics. It combines literature review and a pilot study in a community garden. Findings show appreciation for hydroponics' environmental benefits but uncertainty about non-natural produce. Surprisingly, higher knowledge didn't ensure greater acceptance. Community

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gardens expressed interest, possibly due to their experimental nature. The research concludes that increased knowledge doesn't always drive acceptance due to a focus on social and environmental benefits over productivity [5].

Salis et al. (2020) the study assessed nutrient recovery methods in urban hydroponic agriculture—direct leachate recirculation, chemical precipitation and membrane filtration in a Barcelona greenhouse. DLR had the lowest environmental impact, recovering phosphorus efficiently. Using recovered nutrients reduced global warming impacts by 44–52%. Circular economy principles in urban hydroponics, especially DLR, promote resource efficiency and sustainability [6].

Jung and Kim (2020) the study used Bacillus species to biodegrade mixed fishery wastewater into a biofertilizer. Optimal degradation occurred at a 10:1 ratio, reducing chemical oxygen demand by 69.1% and total nitrogen by 62.0% in 72 hours. The resulting biofertilizer showed high antioxidant activity, met nutrient standards, and significantly enhanced lettuce growth in hydroponics compared to controls. This eco-friendly approach highlights the potential for recycling fishery wastewater into valuable bio fertilizer using Bacillus-mediated biodegradation [7].

Sowmya et al. (2020) the study compared pesto quality from soil-cultivated basil and coriander (SBP, SCP) with hydroponically grown varieties (HBP, HCP). HBP, from hydroponic basil, showed superior bioactive compounds, antioxidants, and sensory attributes. It exhibited higher viscosity, shear stress, and superior stability during storage compared to other pesto types. Overall, HBP emerged as a favorable choice for high-quality pesto production over soil cultivated herbs [8].

Chekli et al. (2021) This study explored using fertilizer-drawn forward osmosis (FDFO) to reuse wastewater for hydroponics. Bench-scale experiments revealed that the hydroponic nutrient solution performed similarly to other solutions in treating synthetic wastewater. It offers all necessary nutrients for plants without requiring additional elements after dilution. Physical cleaning methods like hydraulic flushing and osmotic backwashing effectively restored water flux, showcasing low fouling potential. Pilot studies confirmed the FDFO process produced suitable nutrient concentrations and water quality for hydroponics. Combining FDFO with pressure-assisted osmosis (PAO) could reduce operational costs [9].

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Testing the nutrient solution on hydroponic lettuce showed comparable growth to the control without nutrient deficiencies.

Alipio et al. (2022) This work implemented a smart hydroponics system using a Bayesian Network model to automate crop growth. Sensors and actuators manage light intensity, pH, temperature, and humidity. The Bayesian Network utilizes sensor data to predict optimal actuator values, minimizing sensor value fluctuations compared to manual control. With an 84.53% accuracy in model validation, automatic control resulted in a 66.67% higher crop yield than manual control, showcasing improved efficiency [10].

Zahra et al. (2022) the study compared microbial profiles of hydroponically grown Romaine lettuce with soil-grown lettuce from organic and conventional farming. While no significant differences were found between farming methods, organic non-bagged lettuce showed higher bacteria counts. Both Salmonella and L. monocytogenes were less prevalent in hydroponically grown lettuce. The findings emphasize the need for food safety training across farming methods and further research on environmental factors in hydroponics [11].

Margaret et al. (2022) the study assessed a non-circulating hydroponic system for lettuce in urban Africa, aiming for food security. Conducted in Uganda, it showed positive economic indicators—NPV ($16.37), IRR (12.57%), PI (1.1), NDPBP (4.5) over six cycles. Scenario analyses revealed NPV's sensitivity to discount rates and unit prices. It emphasized hydroponics' profitability for urban food production, supporting sustainability goals, but recommended further studies on different seasons, cities, and vegetables [12].

Kannan et al. (2022) Hydroponic farming offers an alternative to traditional methods, reducing water needs and proving beneficial in degraded soil areas. It's eco-friendly, requiring no pesticides and less water. Unlike conventional farming, it's unaffected by climate change, urbanization, and soil-related challenges. This report explores hydroponics' benefits and limitations through cultivating crops like coriander and leafy vegetables, emphasizing quick yields, disease-free plants, easy management, weed-free growth, and minimal water usage (up to 70–80% savings). It highlights the significance, advantages, and disadvantages of hydroponic farming [13].

Margaret et al. (2022) majority of under-developed countries continue to face a challenge of food insecurity around urban areas resulting from factors such as; limited access to arable land.

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This study aimed at developing a simplified low-tech hydroponic system for growing leafy vegetables alongside testing its economic viability [14].

D'Amico et al. (2023) the study used Life Cycle Assessment to compare high-tech hydroponic and low-tech soil-based greenhouses in Southern Italy. Results favored the high-tech greenhouse, emphasizing reduced environmental impact with automation and renewable energy use [15].

Stelluti et al. (2023) the study investigated how beneficial microorganisms impact saffron cultivation in a hydroponic greenhouse. While not significantly increasing flower or spice yield, they notably boosted safranal content (up to +96%) and enhanced saffron spice's total phenolic content (by 19%). Combining certain microorganisms improved corm yield and size. The findings suggest these bioinoculants stimulate saffron's secondary metabolism, enhancing quality traits, showcasing potential in hydroponics for sustainable saffron cultivation [16].

Tola et al. (2023) This study evaluated three tomato cultivars' response to different salinity levels in a hydroponic greenhouse. Salinity increased spectral reflectance, impacting fruit yield [17].

Valouro-RZ and Feisty-Red had slight yield reductions at higher salinity (6.76-6.79% at 6.0 dS m, 31.77-33.53% at 9.5 dS m), while Ghandowra-F1 showed more tolerance. Grafting on Maxifort rootstock didn't significantly improve yield or salt tolerance. Valouro-RZ and FeistyRed can grow well with up to 6.0 dS m salinity, maintaining fruit yield, and potentially enhancing taste. Further research on rootstock combinations for salinity tolerance is recommended [18].

Gumisiriza et al. (2023) the study assessed non-greenhouse hydroponics for urban farming, comparing leafy lettuce growth to traditional soil methods. It found significant differences ($P<0.05$) in yield for dry matter, fresh weight, and root length. However, hydroponics showed potential similar to soil farming for the number of edible lettuce leaves. The research suggests hydroponics could match traditional methods for leaf production, recommending further exploration of nutritional aspects and extending the analysis to other vegetables [19].

Zhu et al. (2023) The study examined zero-waste hydroponic systems in arid conditions using agricultural waste as nutrients. Three pilot systems were compared: one using aquaponic fish

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sludge, another plant waste digestion, and a control with commercial solution. All showed similar yield (488-539g per shoot) and efficient nutrient recovery (77% N, 65% P). Water use was minimal (~10L/kg of lettuce) and heavy metal risk was low. maintenance, and infrastructure. Challenges include precision issues, calibration, and occlusion, but technological advancements are addressing these concerns. Future work should assess AR's impact on work performance and develop a comprehensive BIM-AR integrative model for validation [20].

3. Experimental Procedure

- PVC pipes of 3 inches dia are bought anddrilled for about 2.5 inches of holes.
- L joints, T joints, end caps, reducers gatewalls, water pump are arranged.
- Then using all the materials finalhydroponic setup was made.
- For the water medium we have mixed thenutrients which contain NPK.
- The water is made to flow 24 hours.

3.1. Observation of Growth Of Plants

Hydroponics farming allows to grow your plants at a very fast rate. Since the plants have unlimitedaccess to nutrients in their roots, they can grow upto 25% faster compared to being planted on soil. Hydroponic production system are used small farmers and commercial enterprises.

Compared to soil-based farming, plants grow considerably faster, healthier, and larger with the hydroponics system. This is because the plants have round-the-clock access to nutrients. Take fenugreek leaves for example. The usual period forgrowth is around two months but with the hydroponics system, it typically takes only one month. In some tests, vegetables and herbs have grown even up to four times faster with an hydroponic system compared to a traditional system.

In some other tests plants have grow up to 25% faster in an hydroponic system which is also an admirable feat. Also, many studies attest to the factthat plants in a soilless system grow larger and they're also more likely to survive compared to when planted in soil. The flavor

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quality of plants in an hydroponics system is also outstanding and at least on par with soil-grown ones.

Here are some popular plants and vegetables that are grown in an hydroponic system with some infoon their growth and harvest time. Tomato were being grown earlier using Nutrient Film Technique (NFT). Saplings were transplanted intothe cups filled with coco peat and introduced into the NFT setup. The tomato plant was doing well initially with hydroponic method, but it was suffered from heat stress later on. The cups used for growing tomatoes had a volume of 69.04cm3. The fruits were small in size as proper nutrition was not available for their development. due to undeveloped root system.

3.2. Test Conducted pH

Test procedure

1. Rinse each test tube with the water sample.
2. Fill the tube to the 5mL line with sample water.
3. While holding a dropper bottle vertically, add 10 drops of Wide Range Indicator Solution.
4. Cap and invert several times to mix.
5. Insert the tube into the Wide Range pHComparator.
6. Record the pH value.

A Low pH level in hydroponics system can affectthe whole system, when pH level drops, the nitrification process decreases and it will also create a stressful condition for the plant that oftenresults in diseases or death. In the hydroponics system plants generally prefer slightly acidic pH level of 6.0 to 6.5 while plants prefer a slightly Alkaline pH level of 6.0 to 8.5 so that balance thepH needs of the plants in our hydroponics system.The ideal range of the pH is between 6.5 to 7.2 for the hydroponics.

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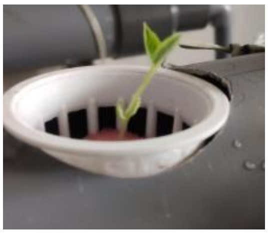
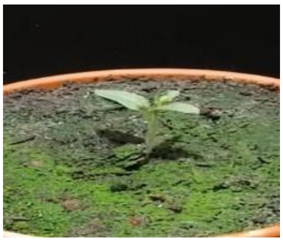


a) Week 2



b) Week 2

a) Week 8

b) Week 8

a) Progress of Tomato plant growth

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Week 2

b) Week 2

a) Week 8

b) Week 8

b) Progress of Fenugreek plant growth

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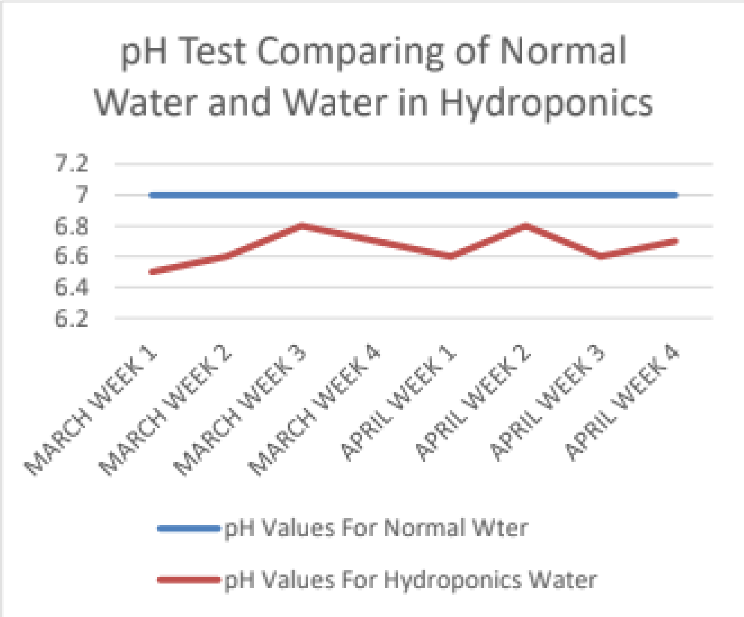

4. Results and Discussions

Hydroponic farming had more growth compared to Land cultivation in both tomato and fenugreek leaves. Since the plants have unlimited access to nutrients in their roots, they can grow up to 25% faster than plants on soil. The growth of plant was noted for a period of 8 weeks. Below figure shows the growth of plants in a different weeks. From the comparison of the figures we can clearly state that the hydroponics has enhanced the growth of plants in greater level.

5. Conclusion

Hydroponics offers a sustainable and efficient method of growing plants without soil. Providing numerous benefits such as increased crop yields, water conservation, and flexibility in location. Its ability to mitigate environmental challenges and produce high-quality produce makes it a promising solution for future agricultural needs. However, successful implementation requires careful consideration of factors like nutrient management,system design, and operational costs to ensure its viability on a large scale. Overall, hydroponics represents a compelling avenue for addressing food security and resource efficiency in agriculture.

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