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RESEARCH ARTICLE

HYDROPONICS: ADVANTAGES AND CHALLENGES IN SOILLESS FARMING

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ABSTRACT

Hydroponics, a soilless method of raising plants using mineral nutrient solutions, represents an important innovation in modern agriculture. This review covers the advantages and challenges associated with hydroponic farming, attempting to provide a full understanding of its potential as an alternative to traditional soil-based agriculture. The major benefits of hydroponics include effective resource management, particularly water and space; increased yields due to controlled settings; and lower pesticide use, leading to sustainable farming practices. However, the adoption of hydroponics is limited by expensive initial setup costs, technological difficulties, and large energy requirements. Effective nutrient management and disease control remain significant problems. This study explores current trends and breakthroughs, such as AI-driven hydroponics, remote cultivation, and the integration of IoT in vertical farming, highlighting the revolutionary potential of these technologies. By overcoming the existing challenges through research and development, hydroponics can play a key role in improving food production, especially in urban areas with limited arable land.

KEYWORDS

Hydroponics, Soilless Farming, Nutrient Management, Sustainable Agriculture and Disease Control in Hydroponics

1. INTRODUCTION

Hydroponics is the use of mineral nutrient solutions in an aqueous solvent to grow plants without soil. It is a significant innovation in modern agriculture (Roy, 2022). Hydroponic systems use various inert media to support plant roots, including peat moss, charcoal, gravel, rock wool, perlite, coco peat, and coconut coir (George and George, 2016). Hydroponic systems are designed to provide plants with the right amount of water, nutrients, and oxygen for optimal growth. They are used in both commercial and private settings to cultivate various plant life, including vegetables, fruits, herbs, and flowers. The origins of hydroponics can be traced back to ancient civilisations, although it has progressed greatly with developments in technology and agricultural methods. Modern hydroponic systems were developed in the mid-20th century (Rajaseger et al., 2023). Today, hydroponics is applied in numerous ways, ranging from small-scale home gardens to huge commercial operations. This evolution has been driven by the desire to increase agricultural efficiency, improve resource utilisation, and reduce the environmental impact of farming operations.

Hydroponics has many advantages, but in order to reach its full potential, a number of challenges must be addressed. High initial setup costs, technical complexities, and significant energy requirements are some of the primary obstacles. Additionally, effective nutrient management and disease control are critical to maintaining healthy crop production in hydroponic systems (Kürklü et al., 2018). This soilless farming technology has the potential to address most of the limitations of traditional soil-based agriculture (Varun Kumar and Verma, 2024). The ability to grow plants in controlled environments has offered new prospects for boosting food production, especially in urban areas where there is limited arable land available (Sharma et al., 2023).

The purpose of this review is to provide a comprehensive examination of hydroponics, focusing on its advantages and challenges. This paper aims to offer insights into hydroponic farming's efficiency, sustainability, and practical implications by analyzing current literature. Through this review, we want to highlight the potential of hydroponics as a viable substitute for traditional agriculture. Also, we want to identify the areas that require further research and development.

2. HISTORICAL DEVELOPMENT

The term 'hydroponics' originates from the Greek word's 'hydro' meaning water and 'ponos' meaning labor. The word was coined in 1929 by Dr. Gericke, a California scientist, and marked the transformation of laboratory methodology into a commercially viable method for plant cultivation. During World War II, the U.S. Army used hydroponic culture to grow food for soldiers stationed on barren Pacific islands. Large-scale hydroponic farms had been established in America, Europe, Africa, and Asia by 1950 (Shrestha and Dunn, 2010). In the present situation, soilless farming can be successfully implemented and considered as an alternate choice for growing nutritious food plants, healthy edible vegetables, or crops (Sharma et al., 2019).

3. TYPES OF HYDROPONIC SYSTEMS

There are various types of hydroponic systems, each having its own particular set of advantages and disadvantages (Nguyen et al., 2016). Some of the most common types of hydroponic systems are tabulated (Table 2).

4. CURRENT TRENDS

In recent years, there have been significant innovations and trends in hydroponics. These advancements have been motivated by the growing demand for sustainable and efficient methods of food production.

4.1 Domotics for Indoor Cultivation-Control Tools

Establishing a hydroponic farming facility requires careful consideration of the location, size, plant species, and necessary tools. Specialised gadgets like lights, aspirators, humidifiers, fans, and heat producers are needed for optimal plant growth. Control devices like thermo-hygrometers, heating systems, and hygrostats are used for improved production. However,

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advanced software-based controls are inadequate for maintaining stable environmental conditions. Advanced software-based controls can handle sensor information and regulate lights, aspirators, and humidifiers through in-built applications (Rajaseger et al., 2023).

Table 1: Types of Hydroponic systems and specific plants.

Hydroponic System	Characteristics	Reference
Wick System	The Wick system is a low-cost hydroponic method that absorbs nutrients via capillary action through roots and inert material. It's useful for teaching hydroponics culture in areas with limited power access and educational institutions. However, it's not suitable for sustainable crop production, especially for small farmers.	(Ferrarezi and Testezlaf, 2014; Thangaiah et al., 2022; Elkazzaz, 2017)
Deep Water Culture (DWC)	The Deep-Water Culture technique in hydroponics involves suspending plant roots in nutrient-rich water, using an air stone for air supply. Plants are grown in net pots, with oxygen, nutrients, pH, and salinity monitored to prevent mold and algae formation.	(Sharma et al., 2019; Singh et al., 2019)
Nutrient Film Technique (NFT)	The nutrient film technique (NFT) exposes plant roots to nutrient-rich water through horizontal pipes. It's more complicated and expensive than media bed culture but offers low evaporation rate. Channel slope, length, and flow rate must be calculated for optimal water flow, oxygen, and nutrients.	(Somerville and Townsend, 2014; Wongkiew et al., 2017)
Drip Irrigation System	The drip hydroponic system involves placing a water tank below the growing tray, where tubes carry water to plants, thereby conserving runoff water and ensuring optimal water distribution.	(Dubey and Nain, 2020)
Aeroponics	Aeroponics is a hydroponic system that uses misting to deliver nutrient-rich water to plants' roots, allowing them to absorb oxygen and nutrients. It's efficient but requires high maintenance to prevent stagnant water and overcrowding. It's not recommended for beginners and can be automated for easier management.	(Santosh and Gaikwad, 2023)
Aquaponics	Aquaponics is a hydroponic technique that mimics a natural ecosystem by using nutrient-rich waste from fish manure, algae, and fish feed in fishponds. Plants act as biofilters, purifying wastewater, which is recycled and released into fishponds, combining plant farming with fish farming.	(Bhargava, 2022)
Ebb and Flow (Flood and Drain)	The method involves submerging plants in a nutritional solution in a repetitive manner, and then draining the solution back into a reservoir. The repeated repetition of this cycle enables the supply of nutrients and oxygen to the roots.	(Rajaseger et al., 2023)

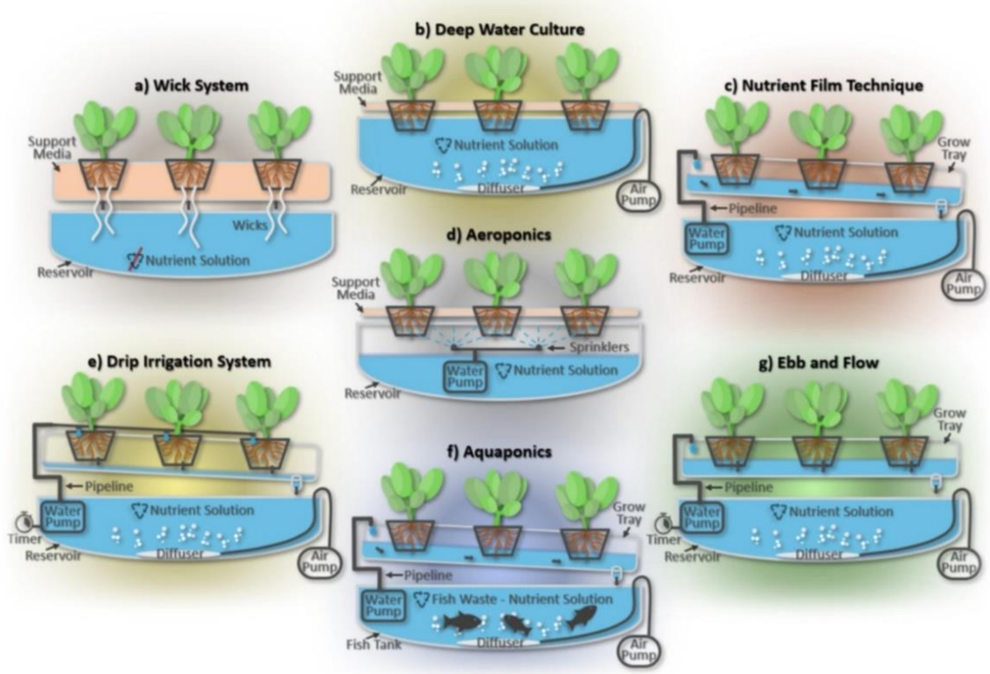

Figure 1: Different types of hydroponic systems. Adapted from (Sousa et al., 2024)

4.2 AI-Driven Hydroponics

Researchers in 2018 utilised an artificial intelligence system to study land and water conservation in hydroponic cultivation of Tomato F1 hybrid Suhyana seed, aiming to optimise plant growth, minimise water usage, and promote sustainable land use practices (Dbritto and Hamdare, 2018). A prototype indoor IoT-based hydroponic control system, linked to Arduino and Raspberry Pi 4, automatically adjusts nutrient and pH levels in a study system (Vincentdo and Surantha, 2023). Sun Park developed an integrated system using IoT-Edge-AI-Cloud to track environmental data in strawberry hydroponics, identifying optimal harvest times. The system collects, organises, and visualises data, using a deep learning algorithm to classify strawberry maturity. The system can be scaled and flexible and was tested for 4 months using Smart Berry Farm images (Park and Kim, 2021).

4.3 Remote cultivation

A remote monitoring system consists of two components: remote telemetry units (RTUs) and master stations. RTUs collect data, while master stations analyse and execute commands. Each device oversees specific agricultural land elements and sends notifications to the central system if any deviation from predetermined parameters occurs (Siregar et al., 2017).

4.4 Aeroponics Technology

Aeroponics is an indoor horticulture technique that uses nutrient-rich mist to suspend plant roots, promoting faster growth and higher yields. It is modern, relevant, and innovative, particularly useful for reforestation in humid climates as it can cultivate large quantities of plants and tree seedlings (Sharma et al., 2019).

4.5 Aquaponics

Aquaponics involves cultivating plants and animals close together, converting fish waste into plant-friendly nitrates and nitrites. Bacteria convert ammonia into nitrates, making aquaponics a primary food source. Plants filter water, making it safe for fish and saving money and biological resources (Love et al., 2015; Love et al., 2015).

4.6 Integration of Iot in Vertical Farming

Vertical farming, a popular trend in hydroponics, involves stacking multiple plant layers vertically to increase crop yield per square foot. This technology reduces water usage and space, but it necessitates a scientific approach that considers factors such as lighting, crop nutrition, growing systems, energy efficiency, construction, and site selection (Gericke, 2015). Vertical farming is a hydroponics trend that stacks multiple plant layers vertically, saving space, reducing water usage, and increasing crop yield per square foot. This technology, which requires protected horticulture systems and multiple growth surfaces, is challenging and expensive. To achieve its benefits, it requires a scientific approach that considers factors such as lighting, crop nutrition, growing systems, energy efficiency, construction, and site selection (Chin and Audah, 2017). Recently, a smartphone app developed in Android Studio allows users to monitor plant development in hydroponic vertical farming systems using Internet of Things technology. Sensors monitor environmental and dietary factors, and data is sent via the Thing-Speak cloud platform, using the Tashi Home Pin fresh system and Arduino and Raspberry Pi as control centres (Kaur et al., 2022).

4.7 Data Acquisition for Cultivation

The effectiveness of yield can be influenced by internal and external factors, including conventional manual monitoring methods. Reliable information gathering and dissemination are crucial for maintaining the authenticity of the agricultural system (Rajaseger et al., 2023). Innovative agriculture combines automated technologies with big data to optimise crop production, eliminating human intervention and labour while machines perform processing work (Pivoto et al., 2018). Globalisation's technological advancements, including IoT and cloud computing, are expected to revolutionise agriculture by increasing automation and machine learning, thereby boosting production (Wolfert et al., 2017). Many large firms and companies are expecting that the vast amount of data, measured in peta and zeta bytes, presents a significant opportunity to generate revenue in multiple ways (Parise, 2016). The Internet of Things (IoT) is a network of interconnected devices, including objects, tools, and vehicles, that exchange data through RFID and sensors, enhancing production by combining natural environments with computing and online resources (Pitakphongmetha et al., 2016; Al Kurdi et al., 2020). In 2017, a study validated the impact of the Internet of Things on a smart hydroponic farming ecosystem. The researchers used sensors and relays to monitor and regulate variables for 27 days. An Arduino 2560-based information recorder collected data from five sensors on six variables, displaying system efficiency instantly (Al Kurdi et al., 2020). Scientist developed a prototype using sensors and actuators to validate aquaponics, using smartphone apps for quick system management and cloud-based storage for regression data assessment (Kyaw and Ng, 2017).

5. Advantages of Hydroponics

5.1 Efficient Use of Resources

The main advantage of hydroponic systems is the efficient use of resources, particularly space and water. There has been a growing presence of innovative technologies in our daily lives. These technologies include smart home technology (also known as domotics), IoT automated growing techniques, and AI-based systems. Interestingly, these technologies have found practical applications in indoor hydroponic productions (Kumar Selvaperumal et al., 2020; Javaid et al., 2022). Thanks to the abundance of knowledge available on the internet, more and more people are beginning to explore different growth strategies for a variety of reasons. As a result, both hydroponic and indoor farming methods are becoming increasingly popular among farmers (Hermawan et al., 2022).

- Water Efficiency: Water conservation is a key benefit of hydroponic systems, which are suitable for water-scarce areas. Water consumption in traditional agriculture can be very high, with evaporation, runoff, and soil absorption responsible for a large amount of irrigation water loss. On the other hand, hydroponics significantly reduces water waste by using a closed-loop system that recycles water. Hydroponic systems can use up to 90% less water than traditional agriculture. This efficiency is achieved through recirculating systems that reuse water, ensuring minimal wastage (Naresh et al., 2024).
- Space Efficiency: Another benefit of hydroponic systems is their efficient use of available space. This is especially important in cities where there is a shortage of land for conventional farming. Hydroponic systems can be layered vertically in vertical farming, allowing the growth of several layers of crops in the same space. Compared to horizontal soil-based farming, this vertical integration maximizes the use of available space, allowing for more food per square meter. Also, hydroponics can reduce the need for long-distance transportation and its accompanying environmental impact by bringing fresh produce closer to urban customers through the use of rooftops, balconies, and other underutilised urban locations (Schnitzler, 2012).

5.2 Higher Yields

Hydroponic farming is often associated with significantly higher yields compared to traditional soil-based agriculture. This advantage stems from several key factors that optimise plant growth and maximise productivity.

5.2.1 Faster Growth

One of the primary reasons hydroponic systems can achieve higher yields. In a hydroponic setup, plants receive a balanced and readily available supply of nutrients directly from their roots. This direct nutrient delivery system ensures that plants can absorb essential minerals more efficiently than they would in soil. Hydroponic plants can grow up to 50% faster than those grown in soil, as the roots do not need to expend energy searching for nutrients (Resh, 2022). In addition to nutrient availability, the controlled environment of hydroponic systems plays a crucial role in speeding up plant growth. To provide ideal growing conditions, variables including light, temperature, humidity, and CO_2 levels can be carefully controlled. Artificial lighting systems such as LEDs, for instance, can give plants the precise spectrum of light required for photosynthesis, increasing the rate of development (Van Iersel and Gianino, 2017).

5.2.2 Controlled Environment

Hydroponics allows for precise control over the growing environment, which is a significant advantage in producing higher yields. In traditional farming, crops are exposed to varying weather conditions, pests, and soil quality issues, all of which can adversely affect growth and yield. In contrast, hydroponic systems create a stable and controlled environment where variables can be adjusted to meet the specific needs of the plants. For instance, hydroponic growers can maintain consistent temperature and humidity levels, which are critical for optimal plant development. By avoiding extreme weather conditions and seasonal changes, plants can grow continuously and more predictably. This consistency leads to multiple cropping cycles within a year, further boosting overall productivity (Touliatos et al., 2016a).

5.2.3 Higher Plant Density

Another factor contributing to higher yields in hydroponic systems is the ability to grow plants at a higher density. Traditional soil farming requires significant spacing between plants to ensure they receive adequate nutrients and light. However, hydroponic systems, especially vertical farming setups, allow for a more compact arrangement of plants. This space efficiency is due to the direct nutrient supply and controlled environment, which mitigate the need for extensive spacing. Vertical farming, a form of hydroponics, exemplifies this advantage by utilising vertical space to grow crops in layers. This method can dramatically increase the amount of produce grown per square foot, making it particularly beneficial in urban areas where land is limited (Despommier, 2011).

5.2.4 Consistent Quality and Yield

Hydroponics not only increases yield, but also improves produce quality and consistency. Plants often grow healthier and more uniformly in size and quality because the growing environment is regulated and adjusted. Commercial farmers, who have to constantly fulfil customer expectations and market standards, would benefit from this uniformity. Research was conducted in 2018 that suggests crops grown through hydroponics, like lettuce and tomatoes, have better quality in terms of flavour, texture, and nutritional value than their soil-grown counterparts (Silva et al., 2018). The capacity to regularly produce high-quality crops can boost farmers' profitability and improve market pricing.

5.3 Pesticide Use is Reduced

5.3.1 Disease Control

One of the significant advantages of hydroponic farming is the reduced need for pesticides. Traditional soil-based agriculture crops are susceptible to a variety of soil-borne diseases and pests. By employing sterile growth media and controlled settings, hydroponics reduces these hazards and the possibility of infections and pest infestations. For example, researcher in 2014 found that root disease prevalence was lower in plants grown hydroponically than in plants grown in soil (Jones, 2014).

5.3.2 Integrated Pest Management (IPM)

When it comes to managing pests, hydroponic systems frequently use Integrated Pest Management techniques that incorporate biological controls such as beneficial insects and microorganisms (Roberts et al., 2020). This method promotes a more sustainable and healthier growing environment by using fewer chemical pesticides.

5.4 Environmental Benefits

- Sustainability: Hydroponics has a significant advantage in terms of sustainability. When compared to traditional agriculture, hydroponic systems can significantly reduce water consumption by recycling nutrients and water. Hydroponic systems can use up to 90% less water than traditional soil-based agriculture (Grewal et al., 2011).
- Reduced Land Degradation: Traditional farming practices can cause soil compaction, erosion, and degradation over time. Because hydroponics does not require soil, these problems are avoided. Also, hydroponics reduces the impact on fertile agricultural fields, allowing them to recover and retain their output because it may be installed in urban areas and on non-arable land (Barbosa et al., 2015).
- Lower Carbon Footprint: Hydroponic farming can also contribute to a lower carbon footprint. Studies have shown that hydroponically grown produce can be cultivated closer to urban centres, reducing the need for transportation and the associated greenhouse gas emissions. Researchers found that urban rooftop farming, including hydroponics, significantly reduces the carbon footprint of food production and distribution by shortening the supply chain and optimising resource use (Sanyé-Mengual et al., 2015).

6. Challenges of Hydroponics

6.1 Initial Costs

Although hydroponic farming systems have many benefits, they also have high initial costs. When evaluating the viability of hydroponic systems, these expenses are critical to consider because they may be a barrier to entry for many prospective farmers.

- Setup Costs: The initial investment in setting up a hydroponic system can be substantial. This includes the cost of materials used to build the growing system, such as grow trays, reservoirs, pumps, and support structures. Additionally, there are costs associated with purchasing or constructing a controlled environment, such as greenhouses or indoor grow rooms equipped with climate control systems. According to a study by Barbosa et al., (2015), the cost of setting up a basic hydroponic system can range from $8 to $12 per square foot for small-scale operations, while commercial systems can be significantly more expensive due to the need for more advanced equipment and larger facilities.
- Technology Costs: For hydroponic systems to continue providing ideal growing conditions, technology is a major factor. This includes automated fertilizer delivery systems, pH and EC (electrical conductivity) monitoring systems, as well as lighting, humidity, and temperature environmental controls. This technology might have a significant initial cost, and because of its complexity, it sometimes requires extra investments in employing or training skilled workers to handle and maintain the equipment. A medium-sized commercial company may have to pay more than $100,000 for a full hydroponic system with integrated technologies (Touliatos et al., 2016b). This includes the cost of sensors, control systems, and backup systems to ensure continuous operation.
- Ongoing Maintenance and Upgrades: Hydroponic systems need regular maintenance and updates after they are first set up in order to continue being effective and productive. Regular maintenance and replacement are required for pumps, filters, and other parts. Furthermore, in order to maintain efficiency and maximize output, hydroponic technological developments may require updates to current systems. According to a study, yearly maintenance expenses can make up 5–10% of the initial setup cost (Resh, 2022b). This covers the cost of general maintenance, software updates, and the replacement of broken parts.

6.2 Technical Expertise

Hydroponics, while offering numerous advantages, also requires a considerable degree of technical expertise for successful implementation and maintenance. This expertise is multidisciplinary and includes data analysis, system engineering, plant biology, and nutrition management.

- Knowledge Requirements: To be able to operate a hydroponic system successfully, an in-depth knowledge of plant physiology and fertiliser uptake systems is required. Hydroponics, compared with traditional soil-based agriculture, uses precise fertiliser solutions to supply plants with essential minerals. For this reason, farmers must be aware of the precise nutrient needs of various crops, as well as the warning signals of nutrient toxicity or deficiencies. The significance of understanding macro- and micronutrient ratios in hydroponic solutions. Common issues that are harmful to plant health and yield, including chlorosis, root rot, and inhibited development, can be avoided with proper management of these nutrients (Bugbee, 2004).
- Monitoring Systems: Hydroponics relies heavily on advanced monitoring systems that use automated controls and sensors to maintain optimal growing conditions. These systems monitor temperature, humidity, electrical conductivity (EC), pH, and other factors. To make timely adjustments, growers need to be skilled at interpreting data from these devices. For instance, maintaining the pH within the optimal range—typically, 5.5 to 6.5 for most crops—is essential for the availability and uptake of nutrients. Hydroponic farming is more complex since these characteristics need to be continuously monitored and adjusted. Even though automated methods can help with some of these difficulties, debugging and performance optimisation still require an adequate understanding of the basic ideas behind them (Velazquez-Gonzalez et al., 2022).

6.3 Nutrient Management

Since plants in hydroponic systems only require nutrient solutions to develop, efficient nutrient management is essential to the system's success. In hydroponic systems, plants are grown in a soilless medium and receive their nutrients from a carefully formulated solution. This solution must contain all essential macro- and micronutrients in precise concentrations to support plant growth. The primary nutrients required include nitrogen (N), phosphorus (P), and potassium (K), often referred to as NPK, along with secondary nutrients like calcium (Ca), magnesium (Mg), and sulphur (S), and trace elements such as iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), and boron (B) (Fathidarehnijeh et al., 2023).

6.4 Energy Consumption

The sustainability and viability of hydroponic farming systems depend significantly on the amount of energy used. Hydroponic systems often need significant energy inputs, especially for artificial lighting, climate control, and the running of pumps and other machinery, even if they have several advantages like increased yields and water efficiency. Artificial lighting is one of the major energy-intensive features of hydroponic systems. Many hydroponic farms use high-intensity discharge (HID) lamps, light-emitting diodes (LEDs), or fluorescent lights to supply the essential spectrum and intensity of light for ideal plant growth, especially those located indoors or in urban areas with limited natural light. These lighting systems have the potential to use large amounts of electricity, which increases operating costs and has an adverse effect on the environment. Studies show that the energy used for artificial lighting in hydroponic systems can account for as much as 60% of overall energy use (Benke & Tomkins, 2017).

Climate control significantly impacts the energy footprint of hydroponic farms. Ensuring the ideal temperatures, humidity levels, and ventilation in the growing environment is critical for plant well-being and efficiency. Typically, this entails the utilisation of heating, ventilation, and air conditioning (HVAC) systems, which can consume a significant amount of energy. The energy requirements for temperature control in hydroponics can vary considerably based on the geographical area and the specific crops being cultivated. However, they continue to constitute a major proportion of the total energy consumption in hydroponics (Pomoni et al., 2023). Pumps for fertilizer solution circulation and aeration also contribute to energy consumption. While these systems are often less energy-intensive compared to lighting and climate control, they are nonetheless crucial for ensuring the health and growth of plants in hydroponic installations.

6.5 Pest and Disease Management

Hydroponic systems can reduce the risk of soil-borne diseases and pests, but they remain vulnerable to other issues such as bacterial infections, fungal infestations, and airborne pests. Water-borne diseases can easily spread across crops in a hydroponic system due to the shared nutrients among all plants (Ikeda et al., 2002). Under soilless conditions, the presence of new and fragile foliage leads to an abundance of sucking pests such as whiteflies, aphids, and thrips, among multiple insect pests (Ravindranath and Bala, 2020; Ravindranath et al., 2019). To reduce the risk of pest and disease outbreaks, it is essential to follow strict hygiene procedures, regularly conduct system maintenance, and cultivate plant varieties that are resistant to pests. Biological controls are a form of integrated pest management (IPM) method that can effectively address issues without heavily relying on chemical interventions.

6.6 Economic Viability

Hydroponic farming offers both potential benefits and significant financial challenges. The significant initial capital investment necessary for establishing hydroponic systems, including expenses for equipment, infrastructure, and technology, could represent a significant challenge for several farmers, especially those who are small-scale and resource-constrained. Additional financial stress is caused by operating expenses, which include energy bills for lighting, heating, and cooling, as well as the requirement for specialised nutrient solutions and frequent maintenance (Resh, 2022c). Higher crop yields and quicker growing cycles, however, are two other possible economic advantages of hydroponics, which can result in more revenue streams. Because hydroponics produces year-round, income may be stabilised by reducing the impact of seasonal changes and climate uncertainties (Jensen and Malter, 1995).

Furthermore, although the market's acceptance of hydroponic produce is increasing, it still faces competition from traditional farming methods. Consumers usually consider hydroponic items to be premium because of their greater quality and pesticide-free nature, which might justify higher market prices. However, the task of attaining extensive market reach and establishing consumer confidence continues to be an enormous challenge (Califano et al., 2024). As the technology improves and becomes more available, economies of scale could reduce costs and enhance the economic feasibility of hydroponic farming, making it a viable alternative to conventional agriculture, especially in urban settings where land availability is limited (Shrouf, 2017).

6.7 Limited Crop Variety

Certain crops may be more adapted to hydroponic growing than others. While many leafy greens, herbs, and certain fruiting plants grow in hydroponic systems, the approach may not be ideal for all types of crops. Root crops with vast root systems, like carrots or potatoes, may have difficulty in particular hydroponic settings (Kumar et al., 2024).

7. Discussion

7.1 Comparative Analysis of Hydroponics with Traditional Soil-Based Farming

In comparing hydroponics with traditional soil-based farming, it becomes obvious that each system contains specific advantages and challenges concerning efficiency, sustainability, and economic viability. Hydroponics exhibits considerable efficiency advantages, notably in water usage and space utilisation, as proven by recent studies (Aishwarya and Vidhya, 2023). However, traditional soil-based farming maintains historical and cultural relevance and often grapples with limits in resource allocation and land availability (Mir et al., 2022).

Concerning sustainability, hydroponic systems offer considerable potential for decreasing environmental impacts, notably in terms of soil conservation and pesticide use reduction (Romeo et al., 2018). However, arguments exist over the long-term ecological consequences and consumption of energy associated with maintaining controlled hydroponic systems (Xydis et al., 2017).

In evaluating economic feasibility, hydroponics frequently implies considerable initial expenditures; however, it offers competitive returns through greater yields and less dependence on external inputs (Thapa et al., 2021). However, traditional agricultural operations typically experience difficulty adjusting to market demands and reducing risks linked to climate variability and soil degradation (Singh and G.S. Singh, 2017). Overall, while hydroponics provides a viable path for solving current agricultural challenges, the combination and integration of both systems may provide a more comprehensive approach to sustainable food production in the future.

7.2 Case Studies

Hydroponics adoption in diverse environments has demonstrated both promising emergent and apparent challenges. A case study focused on open hydroponic systems for tomato crops in Barcelona demonstrated significant achievements in fertiliser and water control. The integrated rooftop greenhouse (i-RTG) setup at the Universitat Autònoma de Barcelona highlighted how novel hydroponic systems may recycle water, electricity, and CO_2, therefore boosting resource efficiency and lowering environmental consequences. The study indicated that while 51% of nutrients were lost through leachates, modifications in nutrient delivery or establishing closed hydroponic systems might greatly enhance nutrient usage efficiency without harming plant growth (Sanjuan-Delmás et al., 2020).

On the other hand, limitations with hydroponic systems were obvious in the study analysing several hydroponic setups for lettuce development. The Nutrient Film Technique (NFT) method was demonstrated to be 6–10% more efficient in improving lettuce output compared to other systems, although difficulties such as nutrient volatilization and retention in substrates like perlite and rockwool were significant challenges. These findings underline the necessity for accurate nutrient management and ongoing innovation to prevent nutrient losses and boost system efficiency (Frasetya et al., 2021).

By reviewing these case studies, we get significant insights into both the advantages and challenges of hydroponic farming, influencing future advancements and uses in diversified agricultural contexts.

Table 2: Comparing Hydroponics and Traditional Soil Farming (Reddy et al., 2023)

Aspect	Hydroponics	Traditional Soil Farming
Water usage	Significantly less, up to 90% less water	More, as water can be lost to soil and evaporation
Space usage	Less space required, suitable for vertical farming	Requires large tracts of land
Location	Can be done anywhere, even in urban settings	Mainly rural locations
Climate control	Year-round farming possible in controlled environments	Dependent on seasonal changes, weather conditions
Soil quality	Not dependent on soil quality	Highly dependent on soil quality and fertility
Pesticide usage	Reduced need for pesticides due to controlled environments	Often requires more pesticides
Growth speed	Faster growth rates due to controlled nutrition	Growth rates depend on various environmental factors
Yield	High yields due to optimized growing conditions	Yield can vary greatly depending on various factors
Startup costs	Higher initial costs for setup and technology	Lower initial costs but might require more long-term investment in soil and pest management
Sustainability	Sustainable; less water and land use	Can be less sustainable due to water, soil, and pesticide usage
Skill required	Requires specific knowledge and training	Traditional farming knowledge often sufficient

7.3 Future Prospects

Hydroponic farming, a method that uses water to provide nutrients, is expected to significantly impact sustainable agriculture. The market is projected to grow by 26% annually, reaching 10,500 metric tonnes by 2023 (Neev Fund, 2023). This rapid growth demonstrates the potential of hydroponic systems to address challenges faced by traditional farming methods.

a. Climate Change Resilience

Climate change poses significant challenges to conventional farming, with extreme weather events, water scarcity, and temperature fluctuations threatening crop production. Hydroponic systems provide a controlled environment that can mitigate the impact of these challenges, ensuring stable crop yields and reducing food system vulnerability. By adapting to changing climatic conditions, hydroponic farming can provide a more reliable and resilient food supply.

b. Resource Efficiency

With a growing global population and limited resources, hydroponic systems excel at resource efficiency. These systems minimise water consumption by recycling and reusing nutrient solutions, with some estimates suggesting a 90% reduction in water usage compared to traditional farming. Additionally, precise nutrient delivery and optimised growing conditions reduce the need for fertilisers and pesticides, resulting in a lower environmental impact.

c. Urban Agriculture and Food Security

As urbanization accelerates, the demand for locally grown, fresh produce increases. Hydroponic systems offer a viable solution for urban agriculture, allowing crops to be grown in limited spaces such as rooftops, vertical farms, and indoor facilities. By reducing food miles and ensuring year-round production, hydroponic farming can enhance food security and provide urban populations with nutritious, pesticide-free crops.

d. Integration with Renewable Energy

The integration of hydroponic systems with renewable energy sources further enhances their sustainability. Solar, wind, and geothermal energy can be used to power hydroponic systems, reducing dependence on fossil fuels and lowering greenhouse gas emissions. This integration contributes to the development of sustainable agricultural practices and helps mitigate the environmental impact of food production.

e. Technological Advancements

Ongoing technological advancements in areas such as artificial lighting, agricultural plastics, and cultivar development are expected to increase crop yields and reduce production costs. Improvements in these associated technologies will make hydroponic systems more cost-competitive with traditional farming methods, driving further adoption and growth in the industry.

f. Governmental Support

Governmental bodies may provide subsidies or support for hydroponic farming due to its potential benefits for water conservation, food production in hostile environments, and employment opportunities for disadvantaged populations. Such support can help overcome the initial high costs associated with setting up hydroponic systems and promote widespread adoption of this sustainable farming method.

8. Conclusion

Hydroponic farming offers significant advantages over traditional soil-based agriculture, such as reduced water usage, efficient space utilisation, faster growth rates, and higher yields. It can be implemented in diverse environments, including urban areas, offering year-round farming under controlled conditions. However, challenges like high initial setup costs, technical complexities, and nutrient management must be addressed. Hydroponic farming can combat climate change, resource scarcity, and urbanization, ensuring stable crop yields and food security. It can also reduce reliance on fossil fuels and greenhouse gas emissions. Future research should focus on optimising nutrient management, developing cost-effective technologies, and promoting local food production through urban planning initiatives. Government support in the form of subsidies and educational programs can help to facilitate widespread adoption.

Data Availability

Data available on request from the authors.

Conflicts of Interest

The authors declare no conflicts of interest.

Reference

Aishwarya, J., and Vidhya, R., 2023. Study on the Efficiency of a Hydroponic Treatment for Removing Organic Loading from Wastewater and Its Application as a Nutrient for the "Amaranthus campestris" Plant for Sustainability. Sustainability, 15, Pp. 7814. https://doi.org/10.3390/su15107814

Al Kurdi, B., Alshurideh, M., and Salloum, S., 2020. Investigating a theoretical framework for e-learning technology acceptance. International Journal of Electrical and Computer Engineering (IJECE), 10, Pp. 6484–6496. https://doi.org/10.11591/ijece.v10i6.pp6484-6496

Barbosa, G., Gadelha, F., Kublik, N., Proctor, A., Reichelm, L., Weissinger, E., Wohlleb, G., and Halden, R., 2015. Comparison of Land, Water, and Energy Requirements of Lettuce Grown Using Hydroponic vs. Conventional Agricultural Methods. International Journal of Environmental Research and Public Health, 12, Pp. 6879–6891. https://doi.org/10.3390/ijerph120606879

Benke, K., and Tomkins, B., 2017. Future food-production systems: Vertical farming and controlled-environment agriculture. Sustainability: Science, Practice and Policy, 13 (1), Pp. 13–26. https://doi.org/10.1080/15487733.2017.1394054

Bhargava, G., 2022. Future Prospects of Vertical and Hydroponic Farming. https://doi.org/10.47611/harp.226

Bugbee, B., 2004. Nutrient management in recirculating hydroponic culture. In Acta Horticulturae. 648, Pp. 112. https://doi.org/10.17660/ActaHortic.2004.648.12

Califano, G., Crichton-Fock, A., and Spence, C., 2024. Consumer perceptions and preferences for urban farming, hydroponics, and robotic cultivation: A case study on parsley. Future Foods, 9, Pp. 100353. https://doi.org/10.1016/j.fufo.2024.100353

Chin, Y., and Audah, L., 2017. Vertical farming monitoring system using the internet of things (IoT). In AIP Conference Proceedings. 1883. https://doi.org/10.1063/1.5002039

Dbritto, G., and Hamdare, S., 2018. An AI Based System Design to Develop and Monitor a Hydroponic Farm. 2018 International Conference on Smart City and Emerging Technology (ICSCET). https://www.semanticscholar.org/paper/An-AI-Based-System-Design-to-Develop-and-Monitor-a-Dbritto-Hamdare/acd5dd7e004d15e5aee352b8b1c210a1690b09fe

Despommier, D., 2011. The vertical farm: Controlled environment agriculture carried out in tall buildings would create greater food safety and security for large urban populations. Journal Für Verbraucherschutz Und Lebensmittelsicherheit, 6, Pp. 233–236. https://doi.org/10.1007/s00003-010-0654-3

Dubey, N., and Nain, V., 2020. Hydroponic—The Future of Farming. International Journal of Environment, Agriculture and Biotechnology, 4 (4), Pp. 857–864. https://doi.org/10.22161/ijeab.54.2

Elkazzaz, A., 2017. Soilless Agriculture a New and Advanced Method for Agriculture Development: An Introduction. Agricultural Research & Technology:Open Access Journal, 3. https://doi.org/10.19080/ARTOAJ.2017.03.555610

Fathidarehnijeh, E., Nadeem, M., Cheema, M., Thomas, R., Krishnapillai, M., and Galagedara, L., 2023. Current perspective on nutrient solution management strategies to improve the nutrient and water use efficiency in hydroponic systems. Canadian Journal of Plant Science, 104. https://doi.org/10.1139/CJPS-2023-0034

Ferrarezi, R., and Testezlaf, R., 2014. Performance of Wick Irrigation System using Self-Compensating Troughs with Substrates for Lettuce Production. Journal of Plant Nutrition, In press, In press. https://doi.org/10.1080/01904167.2014.983127

Frasetya, B., Harisman, K., and Ramdaniah, N. A. H., 2021. The effect of hydroponics systems on the growth of lettuce. IOP Conference Series: Materials Science and Engineering, 1098 (4), 042115. https://doi.org/10.1088/1757-899X/1098/4/042115

George, P., and George, N., 2016. Hydroponics-(Soilless Cultivation Of Plants) For Biodiversity Conservation.

Gericke, W.f., 2015. The Complete Guide To Soilless Gardening. http://archive.org/details/in.ernet.dli.2015.271694

Grewal, H., Maheshwari, B., and Parks, S., 2011. Water and nutrient use efficiency of a low-cost hydroponic greenhouse for a cucumber crop: An Australian case study. Agricultural Water Management, 98, Pp. 841–846. https://doi.org/10.1016/j.agwat.2010.12.010

Hermawan, H., Uddin, N., and Darajat, T., 2022. A Development of Web

Application for Hydroponic Monitoring Systems. E3S Web of Conferences, 348, 00024. https://doi.org/10.1051/e3sconf/202234800024

Ikeda, H., Koohakan, P., and Jaenaksorn, T., 2002. Problems and countermeasures in the re-use of the nutrient solution in soilless production. Acta Horticulturae, 578, Pp. 213–219. https://doi.org/10.17660/ActaHortic.2002.578.26

Javaid, M., Haleem, A., Singh, R., and Suman, R., 2022. Enhancing smart farming through the applications of Agriculture 4.0 technologies. International Journal of Intelligent Networks, 3. https://doi.org/10.1016/j.ijin.2022.09.004

Jensen, M. H., and Malter, A., 1995. Protected Agriculture: A Global Review. 253.

Jones, Jr., 2014. Complete Guide for Growing Plants Hydroponically (0 ed.). CRC Press. https://doi.org/10.1201/b16482

Kaur, G., Upadhyaya, P., and Chawla, P., 2022. IoT Based Mobile Application for Monitoring of Hydroponic Vertical Farming, Pp. 4. https://doi.org/10.1109/ICRITO56286.2022.9964872

Kumar Selvaperumal, Assoc. Prof. Dr. S., Lakshmanan, R., Guedi, M., Perumal, S., & Abdulla, R., 2020. Automated smart hydroponics system using internet of things. International Journal of Electrical and Computer Engineering (IJECE), 10, 6389. https://doi.org/10.11591/ijece.v10i6.pp6389-6398

Kumar, A., Thakur, V., Singh, J., and Rohilla, H., 2024. Hydroponics, a soilless gardening, a new way, Pp. 362–375).

Kürklü, A., Ghafoor, Dr. A., Khan, Engr. F., and Ali, Q., 2018. A Review on Hydroponic Greenhouse Cultivation for Sustainable Agriculture. International Journal of Agriculture Environment and Food Sciences, 2, Pp. 59–66. https://doi.org/10.31015/jaefs.18010

Kyaw, T., and Ng, A., 2017. Smart Aquaponics System for Urban Farming. Energy Procedia, 143, Pp. 342–347. https://doi.org/10.1016/j.egypro.2017.12.694

Love, D., Fry, J., Li, X., Hill, E., Genello, L., Semmens, K., and Thompson, R., 2015. Commercial aquaponics production and profitability: Findings from an international survey. Aquaculture, 435, Pp. 67–74. https://doi.org/10.1016/j.aquaculture.2014.09.023

Love, D., Uhl, M., and Genello, L., 2015. Energy and Water Use of a Small-Scale Raft Aquaponics System in Baltimore, Maryland, United States. Aquacultural Engineering, Pp. 68. https://doi.org/10.1016/j.aquaeng.2015.07.003

Mir, M., Naikoo, N., Kanth, R., Bahar, F., Bhat, M., Nazir, D., Mahdi, S., Amin, Z., Singh, L., Raja, W., Saad, A., Bhat, T., Palmo, T., and Ahngar, T., 2022. Vertical farming: The future of agriculture: A review.

Naresh, R., J, S., Beese, S., and singh, M., 2024. Role of Hydroponics in Improving Water-Use Efficiency and Food Security. International Journal of Environment and Climate Change, 14, Pp. 608–633. https://doi.org/10.9734/IJECC/2024/v14i23976

Neev Fund., 2023. (4) Hydroponic Farming: The Way of the Future | LinkedIn. https://www.linkedin.com/pulse/hydroponic-farming-way-future-neev-fund/

Nguyen, N., McInturf, S., and Mendoza-Cozatl, D., 2016. Hydroponics: A Versatile System to Study Nutrient Allocation and Plant Responses to Nutrient Availability and Exposure to Toxic Elements. Journal of Visualized Experiments, 2016. https://doi.org/10.3791/54317

Parise, S., 2016. Big data: A revolution that will transform how we live, work, and think, by Viktor Mayer-Schonberger and Kenneth Cukier: London, UK, Eamon Dolan/Mariner, 2014, 272 pp., $10 (paperback), $10 (Kindle edition), ISBN 978-0544227750. Journal of Information Technology Case and Application Research, 18 (3), Pp. 186–190. https://doi.org/10.1080/15228053.2016.1220197

Park, S., and Kim, J., 2021. Design and Implementation of a Hydroponic Strawberry Monitoring and Harvesting Timing Information Supporting System Based on Nano AI-Cloud and IoT-Edge. Electronics, 10, 1400. https://doi.org/10.3390/electronics10121400

Pitakphongmetha, J., Boonnam, N., Wongkoon, S., Horanont, T., Somkiadcharoen, D., and Prapakornpilai, J., 2016. Internet of things for planting in smart farm hydroponics style, Pp. 5. https://doi.org/10.1109/ICSEC.2016.7859872

Pivoto, D., Waquil, P. D., Talamini, E., Finocchio, C. P. S., Dalla Corte, V. F., and de Vargas Mores, G., 2018. Scientific development of smart farming technologies and their application in Brazil. Information Processing in Agriculture, 5 (1), Pp. 21–32. https://doi.org/10.1016/j.inpa.2017.12.002

Pomoni, D., Koukou, M., Vrachopoulos, M., and Vasiliadis, L., 2023. A Review of Hydroponics and Conventional Agriculture Based on Energy and Water Consumption, Environmental Impact, and Land Use. Energies, 16, 1690. https://doi.org/10.3390/en16041690

Rajaseger, G., Chan, K. L., Yee Tan, K., Ramasamy, S., Khin, M. C., Amaladoss, A., & Kadamb Haribhai, P., 2023. Hydroponics: Current trends in sustainable crop production. Bioinformation, 19 (9), Pp. 925–938. https://doi.org/10.6026/97320630019925

Ravindranath, N., and Bala, S., 2020. Bio-efficacy of Some Newer Insecticides against Aphis gossypii and Amrasca biguttula infesting Bt Cotton. Pesticide Research Journal, 32, Pp. 134–139. https://doi.org/10.5958/2249-524X.2020.00017.5

Ravindranath, N., Bala, S., and Sarkar, A., 2019. Population dynamics of aphid (Aphis gossypii) and jassid (Amrasca biguttula biguttula) in Bt cotton.

Reddy, K., Sreekumar, G., Mishra, R., and Saikanth, D., 2023. Future of Hydroponics in Sustainable Agriculture. Pp. 114–127.

Resh, H., 2022a. Hydroponic Food Production: A Definitive Guidebook for the Advanced Home Gardener and the Commercial Hydroponic Grower. https://doi.org/10.1201/9781003133254

Resh, H., 2022b. Hydroponic Food Production: A Definitive Guidebook for the Advanced Home Gardener and the Commercial Hydroponic Grower. https://doi.org/10.1201/9781003133254

Resh, H., 2022c. Hydroponic Food Production: A Definitive Guidebook for the Advanced Home Gardener and the Commercial Hydroponic Grower. https://doi.org/10.1201/9781003133254

Roberts, J., Bruce, T., Monaghan, J., Pope, T., Leather, S., and Beacham, A., 2020. Vertical farming systems bring new considerations for pest and disease Management. Annals of Applied Biology, 176. https://doi.org/10.1111/aab.12587

Romeo, D., Blikra Vea, E., and Thomsen, M., 2018. Environmental Impacts of Urban Hydroponics in Europe: A Case Study in Lyon. Procedia CIRP, 69, Pp. 540–545. https://doi.org/10.1016/j.procir.2017.11.048

Roy, D., 2022. Hydroponics: Soil-less Farming Technique. 03, Pp. 43–45.

Sanjuan-Delmás, D., Josa, A., Muñoz, P., Gassó, S., Rieradevall, J., and Gabarrell, X., 2020. Applying nutrient dynamics to adjust the nutrient-water balance in hydroponic crops. A case study with open hydroponic tomato crops from Barcelona. Scientia Horticulturae, 261, 108908. https://doi.org/10.1016/j.scienta.2019.108908

Santosh, D. T., and Gaikwad, D., 2023. Advances in Hydroponic Systems: Types and Management, Pp. 16–28).

Sanyé-Mengual, E., Oliver-Solà, J., Montero, J., and Rieradevall, J., 2015. An environmental and economic life cycle assessment of rooftop greenhouse (RTG) implementation in Barcelona, Spain. Assessing new forms of urban agriculture from the greenhouse structure to the final product level. The International Journal of Life Cycle Assessment, Pp. 20. https://doi.org/10.1007/s11367-014-0836-9

Schnitzler, W., 2012. Urban Hydroponics for Green and Clean Cities and for Food Security. Acta Horticulturae, 1004, Pp.13–26. https://doi.org/10.17660/ActaHortic.2013.1004.1

Sharma, N., Acharya, S., Kumar, K., Singh, N., and Chaurasia, O., 2019. Hydroponics as an advanced technique for vegetable production: An overview. Journal of Soil and Water Conservation, 17, Pp. 364–371. https://doi.org/10.5958/2455-7145.2018.00056.5

Sharma, S., Lishika, B., Shahi, A., and Kaushal, S., 2023. Hydroponics: The Potential to Enhance Sustainable Food Production in Non-Arable Areas. Current Journal of Applied Science and Technology, 42. https://doi.org/10.9734/CJAST/2023/v42i394253

Shrestha, A., and Dunn, B., 2010. Hydroponics. Oklahoma Cooperative Extension Service. https://shareok.org/bitstream/handle/11244/50283/oksd_hla_6442_2010-03.pdf?sequence=1

Shrouf, A., 2017. Hydroponics, Aeroponic and Aquaponic as Compared with Conventional Farming. American Scientific Research Journal for Engineering, Technology, and Sciences, 27, Pp. 247–255.

Silva, B. N., Khan, M., and Han, K., 2018. Components, and open challenges in smart cities. Sustainable Cities and Society.

Singh, H., Dunn, B. L., Payton, M., and Brandenberger, L., 2019. Selection of Fertilizer and Cultivar of Sweet Pepper and Eggplant for Hydroponic Production. Agronomy, 9 (8), Article 8. https://doi.org/10.3390/agronomy9080433

Singh, R., and Singh, G. S., 2017. Traditional agriculture: A climate-smart approach for sustainable food production. Energy, Ecology and Environment, 2 (5), Pp. 296–316. https://doi.org/10.1007/s40974-017-0074-7

Siregar, B., Efendi, S., Pranoto, H., Ginting, R., Andayani, U., and Fahmi, F., 2017. Remote monitoring system for hydroponic planting media, Pp. 6. https://doi.org/10.1109/ICTSS.2017.8288884

Somerville, M., and Townsend, J., 2014. A student-centered approach to designing teaming experiences. 2014 IEEE Frontiers in Education Conference (FIE) Proceedings, Pp. 1–2. https://doi.org/10.1109/FIE.2014.7044403

Sousa, R. de, Bragança, L., da Silva, M. V., and Oliveira, R. S., 2024. Challenges and Solutions for Sustainable Food Systems: The Potential of Home Hydroponics. Sustainability, 16 (2), Article 2. https://doi.org/10.3390/su16020817

Thangaiah, A., Gunalan, S., & Maheswari, U., 2022. Soilless farming of vegetable crops: An overview.

Thapa, G., GC, A., and Pandey, A., 2021. Economic viability of hydroponic system: A case from Kathmandu valley. 21, Pp. 203–210.

Touliatos, D., Dodd, I., and Mcainsh, M., 2016a. Vertical farming increases lettuce yield per unit area compared to conventional horizontal hydroponics. Food and Energy Security, 5. https://doi.org/10.1002/fes3.83

Touliatos, D., Dodd, I., and Mcainsh, M., 2016b. Vertical farming increases lettuce yield per unit area compared to conventional horizontal hydroponics. Food and Energy Security, 5. https://doi.org/10.1002/fes3.83

Van Iersel, M., and Gianino, D., 2017. An Adaptive Control Approach for Light-emitting Diode Lights Can Reduce the Energy Costs of Supplemental Lighting in Greenhouses. HortScience, 52, Pp. 72–77. https://doi.org/10.21273/HORTSCI11385-16

Varun Kumar, T., and Verma, R., 2024. A Comprehensive Review on Soilless Cultivation for Sustainable Agriculture. Journal of Experimental Agriculture International, 46, Pp. 193–207. https://doi.org/10.9734/JEAI/2024/v46i62470

Velazquez-Gonzalez, R. S., Garcia-Garcia, A. L., Ventura-Zapata, E., Barceinas-Sanchez, J. D. O., & Sosa-Savedra, J. C. (2022). A Review on Hydroponics and the Technologies Associated for Medium- and Small-Scale Operations. Agriculture, 12 (5), Pp. Article 5. https://doi.org/10.3390/agriculture12050646

Vincentdo, V., and Surantha, N., 2023. Nutrient Film Technique-Based Hydroponic Monitoring and Controlling System Using ANFIS. Electronics, 12, 1446. https://doi.org/10.3390/electronics12061446

Wolfert, S., Ge, L., Verdouw, C., and Bogaardt, M.-J., 2017. Big Data in Smart Farming – A review. Agricultural Systems, 153, Pp. 69–80. https://doi.org/10.1016/j.agsy.2017.01.023

Wongkiew, S., Hu, Z., Chandran, K., Lee, J. W., and Khanal, S. K., 2017. Nitrogen transformations in aquaponic systems: A review. Aquacultural Engineering, 76, Pp. 9–19. https://doi.org/10.1016/j.aquaeng.2017.01.004

Xydis, G., Liaros, S., and Botsis, K., 2017. Energy demand analysis via small scale hydroponic systems in suburban areas—An integrated energy-food nexus solution. The Science of the Total Environment, 593–594, Pp. 610–617. https://doi.org/10.1016/j.scitotenv.2017.03.170