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ECONOMIC BENEFITS OF USING AN INDUSTRIAL HYDROPONIC MULTI-TIER SYSTEM

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Abstract
This article explores the economic benefits of using industrial hydroponic multi-tier systems. The study aims to analyze the efficiency, sustainability, and successful applications of these systems in urban and rural settings. The methods employed include a literature review of recent research on hydroponic technology, focusing on economic feasibility, environmental impact, and practical case studies. The key results highlight the economic advantages, such as cost savings and increased productivity, along with environmental benefits, including water conservation and reduced carbon footprint. The conclusions point to hydroponics as a viable and sustainable solution for modern agriculture, particularly in urban environments. The novelty of the work lies in synthesizing diverse perspectives on hydroponic systems, emphasizing their potential for revolutionizing food production and addressing global sustainability challenges.

Keywords Hydroponic, multi-tier, urban agriculture, economic benefits, sustainability, water conservation, vertical farming, renewable energy, environmental impact, innovation.

INTRODUCTION

Hydroponics, a method of growing plants without soil using mineral nutrient solutions, has attracted attention due to its potential to revolutionize agricultural productivity. In multilevel systems, hydroponics becomes even more efficient, maximizing space utilization and increasing crop yields (Figure 1) [1]. These systems have proven to be particularly advantageous in urban environments where space is limited and demand for fresh produce is high [2]. The use of solar energy in hydroponics has also become a key element, aligning with sustainable energy initiatives and reducing operating costs [3].

Figure 1 - Multilevel hydroponics systems

The relevance of hydroponics in modern agriculture must be considered. As the world's population continues to grow to 8.108 billion in May 2024, food security is becoming a pressing issue. Land availability, water scarcity, and environmental degradation often challenge traditional farming methods. Hydroponic systems offer a solution to these problems by using less water and land and minimizing environmental impact [2]. Economic benefits are associated with increased crop yields, reduced labor costs, and the ability to grow crops year-round, regardless of external weather conditions [4].

Multilevel hydroponic systems have proven to be a viable approach to meet the growing needs of urban populations. These systems make efficient use of vertical space, allowing different crops to be grown in compact areas. This design is particularly advantageous in urban areas where space is limited and traditional agriculture is not feasible [1]. The economic benefits of such systems are evident in their ability to produce high-quality produce locally, reducing transportation costs and minimizing food waste [5].

In addition, the integration of solar energy into hydroponic systems increases their economic viability. Solar-powered hydroponics reduces dependence on conventional energy sources, lowers operating costs, and contributes to sustainable development goals [3]. This approach is in line with global renewable energy trends, making hydroponics a forward-thinking investment.

THEORETICAL PART

Hydroponics is an innovative method of farming and offers an alternative to traditional soil-based farming. Nutrient-rich aqueous solutions are used to grow plants, providing a sustainable and efficient approach to food production. This concept has expanded significantly in industrial applications, especially in multi-level systems that maximize space and productivity.

The basic idea behind hydroponics is to eliminate the need for soil by delivering nutrients directly to plant roots through aqueous solutions. This system can be implemented in a variety of setups such as nutrient film technology, deep-water culture, aeroponics, etc. (Figure 2). Each method has unique advantages, but they all have the benefit of precise control of the plant's environment, resulting in optimized growth and yield [6].

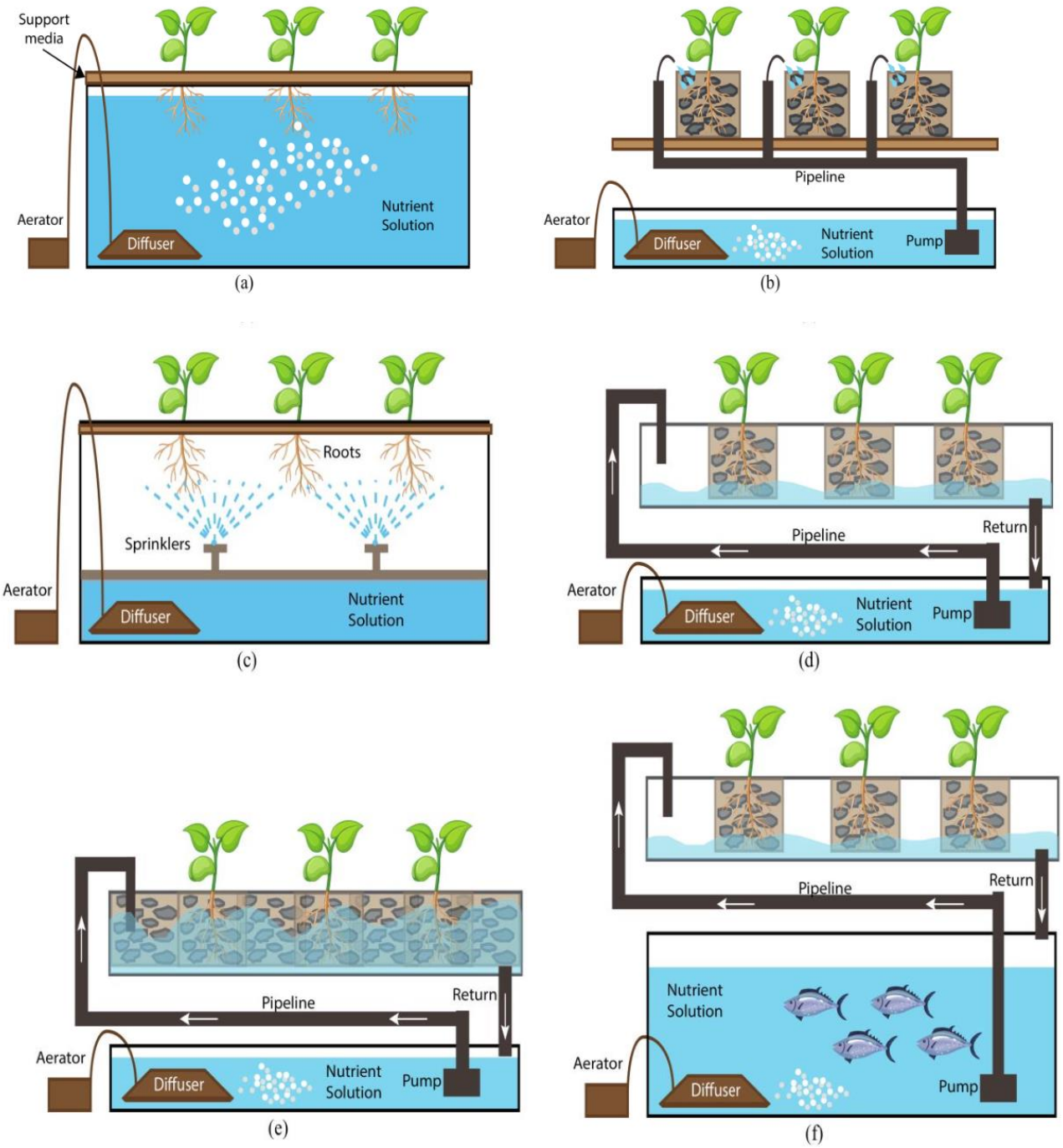

Figure 2 – Types of hydroponic systems [6]

(a) Deep Water Culture. (b) Drip System. (c) Aeroponics. (d) Nutrient Film Technique (NFT). (e) Ebb and flow. (f) Aquaponics

Industrial hydroponic systems typically operate in controlled environments such as greenhouses or indoor facilities. These controlled environments offer several advantages. For example, hydroponic systems can use up to 90% less water than traditional agriculture because the water is recycled and reused [7]. In addition, because there is no need for soil, hydroponics eliminates soil-borne disease and pest problems, reducing the need for pesticides. This environmentally friendly approach is in line with the goals of sustainable agriculture, helping to address problems such as water scarcity and pollution [2].

Hydroponic systems have demonstrated their usefulness in various industries, especially in urban agriculture. With increasing urbanization, there is a growing demand for locally produced food, and hydroponics offers a viable solution. Multi-tier hydroponic systems are particularly effective in urban environments where space is limited. These systems allow vertical farming, maximize space efficiency, and allow year-round crop production [1]. The ability to control the growing environment leads to higher yields and consistent crop quality, which is important to meet the needs of urban consumers [5].

The benefits of hydroponics extend beyond urban agriculture. In rural areas where traditional agriculture may face problems such as water shortage or poor soil quality, hydroponics offers an alternative. Precise control over the supply of water and nutrients ensures that crops receive optimal growing conditions. In addition, hydroponic systems can be adapted to different crops, allowing farmers to diversify their production and respond to market needs [4].

The integration of renewable energy sources such as solar energy further enhances the sustainability of hydroponic systems. Solar-powered hydroponics is an emerging trend that aligns with green energy initiatives and reduces operating costs (Figure 3) [3]. This link between hydroponics and renewable energy supports the goal of sustainable and resilient food production systems.

Figure 3 - Schematic diagram of a solar-powered hydroponic pump [3]

Hydroponic technology continues to evolve, including advances in artificial intelligence and machine learning to optimize growing methods. Artificial intelligence (AI) can improve the accuracy of nutrient balancing, disease prediction, and environmental control, leading to increased efficiency and productivity [6]. These technological innovations promise to further improve the economic and environmental benefits of hydroponics, positioning it as a key player in future agricultural practices.

Thus, industrial hydroponics, especially multilevel systems, offers many advantages in terms of sustainability, efficiency, and urban integration. The implementation of hydroponics in various environments, coupled with technological advances, positions it as a promising solution to today's agricultural challenges.

ECONOMIC EFFICIENCY AND ADVANTAGES

Hydroponic systems have attracted attention for their potential economic efficiency and benefits in modern agriculture. These systems offer a unique combination of sustainability and profitability, especially when integrated with renewable energy sources. The economic benefits of hydroponics can be seen in a variety of contexts, including urban agriculture, renewable energy integration, and aquaponics.

Hydroponic systems allow precise control of nutrient delivery, resulting in high yields with minimal resource utilization. This efficiency has been demonstrated at an industrial scale, where hydroponics outperforms conventional farming methods regarding water and nutrient utilization [7]. In a divided multi-loop aquaponics system, where fish and plants are grown separately but synergistically, hydroponics has achieved higher productivity than traditional methods. The integrated approach of this system reduces waste and maximizes resource utilization, demonstrating significant economic efficiency.

One of the key factors affecting the economic performance of hydroponic systems is energy consumption. Utilizing solar energy has emerged as a viable solution to reduce operating costs and increase economic returns. In a pilot study conducted in Indonesia, solar-powered hydroponics proved to be economically viable as it provides 24/7 operation of water pumps and reduces dependence on conventional energy sources [3]. This approach is in line with the green economy program and offers a sustainable alternative to conventional energy sources.

Also, hydroponics has proven to be economically viable in urban agriculture where space is limited and demand for fresh produce is high. An investment plan for a hydroponic tomato greenhouse in Western Greece showed positive economic viability: net present value (NPV) and internal rate of return (IRR) indicate profitability over five years [4]. The study examined different economic scenarios and found that hydroponics remains economically viable under different market conditions, emphasizing its sustainability as an investment.

Aquaponics, a system that combines hydroponics with aquaculture, provides additional economic benefits by integrating fish and plant production. Benefit-cost analysis showed that the aquaponic system is economically feasible and shows a positive net present value [8]. This system utilizes the symbiotic relationship between fish and plants: fish waste provides nutrients for plant growth and plants filter water for fish. Dual production provides economic benefits by diversifying income streams and improving resource utilization efficiency.

In summary, hydroponic systems offer significant economic efficiencies and benefits in a variety of settings. From urban agriculture to integrated aquaponic systems, hydroponics has demonstrated its potential as a sustainable and profitable agricultural practice.

ENVIRONMENTAL BENEFITS

Industrial hydroponics, as a modern agricultural practice, offers significant environmental benefits, contributing significantly to sustainable development. Hydroponic systems are environmentally friendly by addressing several key issues such as waste management, nutrient recycling, and resource conservation. Integrating

hydroponics with other systems such as aquaponics increases its environmental sustainability. For example, a study on urban agriculture found that alternatives to nutrient recovery in hydroponic systems had a positive impact on the environment, especially when using techniques such as direct leachate recycling (DLR) and membrane filtration (MF). These approaches have helped to restore key nutrients such as phosphorus, magnesium, and calcium, helping to reduce eutrophication and improve nutrient efficiency [2].

Hydroponic systems are also beneficial for water management. A study was conducted in Saudi Arabia comparing the water use efficiency and economic viability of hydroponic and conventional growing systems for green fodder production. The hydroponic system demonstrated significantly higher water use efficiency, addressing water scarcity problems in the country. A study showed that although conventional cultivation provides lower costs, the hydroponic system excels in water conservation, making it a valuable option for arid regions [9].

The environmental benefits of hydroponics are further emphasized by its contribution to reducing greenhouse gas emissions. Hydroponic systems minimize the need for land and often require less energy, which contributes to lower carbon dioxide emissions compared to conventional agriculture. In addition, the controlled environment of hydroponic systems reduces the use of pesticides and herbicides, minimizing the release of chemicals into the environment [2].

Hydroponics also supports biodiversity by allowing a wide variety of crops to be grown in different environments. This flexibility contributes to ecological sustainability, especially in urban settings where biodiversity is often at risk due to habitat loss [9].

Thus, we note that the environmental benefits of industrial hydroponics are clear. The systems promote sustainable development through efficient resource utilization, nutrient recycling, and environmental protection. Hydroponics offers significant benefits for water management and environmental health, making it a key component of sustainable agriculture.

EXAMPLES OF SUCCESSFUL APPLICATIONS

Vertical vegetable cultivation has emerged as a promising solution to meet the needs of urban populations and ensure food security while reducing production costs. One prominent example of this success is the development of tomato varieties adapted for multi-tier hydroponic plants. This approach is in line with the growing trend of urbanization, which requires efficient food production in limited spaces [1].

The Federal Scientific Center for Vegetable Production in Russia developed the first tomato varieties 'Natasha' and 'Timosha' specifically for vertical vegetable production. The process involved the creation of a model of a new tomato form suitable for tiered hydroponic structures. The study utilized a collection of 692 tomato accessions and focused on the development of varieties as part of the processing chain. The economic performance of these varieties on tiered narrow-stem hydroponics showed significant advantages over conventional cultivation methods [1].

These successes emphasize the potential of tiered hydroponic systems in urban agriculture. The use of hydroponic systems with narrow racks allows for efficient space utilization and stable production. In addition, this method provides economic benefits by optimizing resource utilization and increasing crop yields.

CONCLUSION

In exploring the topic of industrial hydroponic tiered systems, the evidence presented in this paper illustrates the multifaceted benefits of these systems. From economic efficiency to environmental sustainability to the successful application of multilevel systems in urban agriculture, it is evident that hydroponics is having a transformative impact on modern farming practices. The integration of solar energy and advances in technology such as artificial intelligence further enhances the value of these systems.

Reflecting on this theme, it is worth emphasizing

the potential of hydroponics as a sustainable solution for food production, especially in urban environments where space is limited. The ability to grow crops vertically not only maximizes space but also enables year-round production, addressing food security concerns. Moreover, the integration of renewable energy sources brings hydroponics in line with global sustainability goals, making it a promising direction for future agricultural development.

Examples of successful hydroponic installations demonstrate the feasibility of this approach and highlight its potential to revolutionize agriculture. With a growing world population and increasing demand for sustainable food production, hydroponics offers a viable solution that combines economic viability with environmental protection. In the future, agriculture is likely to see an increased reliance on such innovative systems, contributing to a more resilient and sustainable global food supply chain.

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