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PLANT GROWING IN HYDROPONIC SYSTEM: CASE OF STUDY

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Abstract: Hydroponics is an innovative plant production system in which crops are cultivated in a nutrient, often with the support of inert substrates such as expanded clay, perlite, coconut fiber or rockwool. This method is typically implemented in controlled environments, including greenhouses or high tunnels, where key growth parameters (pH, electrical conductivity, nutrient concentration, temperature, light intensity, oxygen availability and air circulation) can be precisely regulated. Although hydroponic systems require higher initial investments, these costs are gradually offset through increased productivity and more efficient resource use. As a green innovation, hydroponics reduces dependence on climatic variability, limits exposure to pests and pathogens and supports year-round production with reduced water consumption and environmental impact. As part of this research, a case study was conducted to evaluate hydroponic cultivation under simplified, home-scale conditions. The goal was to identify the most critical control points in the system, including the sensitivity of pH and electrical conductivity adjustments, nutrient balance, temperature fluctuations and light availability. Several combinations of environmental and nutrient conditions were tested to determine which setups yield the most stable plant growth and highest biomass production. The results highlight the importance of continuous monitoring, particularly during early developmental stages, and demonstrate that even small deviations in nutrient concentration or environmental parameters can significantly affect plant performance. Findings from the case study provide practical insights into the limitations, risks and optimal management strategies for small-scale hydroponic systems, contributing to a broader understanding of hydroponics as a sustainable and accessible agricultural approach.

Keywords: Climate-smart agriculture, Hydroponics, Nutrient solution management, Sustainable production

INTRODUCTION

Hydroponics refers to cultivating plants in water enriched with essential nutrients rather than in traditional soil. The word itself comes from Greek, combining "hydro" (water) and "ponos" (work). In hydroponic setups, plant roots are typically stabilized using inert substrates such as peat moss, charcoal, gravel, rock wool, perlite, coco peat, or coconut coir. These systems are designed to precisely regulate water, nutrient levels, and oxygen availability, creating conditions that favor optimal plant growth (Rajaseger et al., 2023). Today, hydroponic techniques are applied both in commercial production and in household settings for growing numerous types of crops, including vegetables, fruits, herbs, and ornamental plants. Although soil-free cultivation has ancient origins, the modern form of hydroponics emerged in the mid-20th century as a response to the need for increased food production in areas where space and resources are limited (Rodríguez-Delfín et al., 2017).

The history of the development of hydroponics, that is, the cultivation of plants without the use of soil, in a nutrient solution, spans a very long period from ancient civilizations to modern, highly automated production systems. Based on the major achievements that stimulated the development of this innovative method, several phases can be distinguished: the ancient and medieval period; the period from the 17th to the 19th century; the period from 1930 to 1950; from 1960 to 1990; and the contemporary phase, from 2000 to the nowadays (Walters et al., 2020). Although it is believed that the Hanging Gardens were created utilizing the first known application of hydroponic cultivation, there are claims that the prototype and beginning of hydroponic is “chinampa” as a raised field on a small artificial island on a freshwater lake surrounded by canals and ditches (Ebel, 2020). The period from the 17-19th century marks an important advancement in the development of hydroponics, as it was during this time that the scientific foundation for this method was established particularly regarding the chemical composition of nutrient solutions, the selection of plant species, and other key aspects of the technique. In 1929, William Frederick Gericke from the University of California, Berkeley, began advocating the application of hydroponic concepts for growing agricultural crops and introduced the term hydroponics, formed from the Greek words for water and labor. A decade later, in 1940, Gericke widely regarded as the pioneer whose work laid the groundwork for all modern hydroponic systems released his book “The Complete Guide to Soilless Gardening.” This publication presented his initial nutrient solution formulas, which included both macro- and micronutrient salts tailored for plants cultivated without soil. Much of his experimental work centered on vegetable crops, with tomatoes being his primary model species (Torabi et al., 2012).

Over the past few decades, hydroponics has evolved into a key component of modern, technology-driven agriculture, incorporating features such as automated sensors, digital monitoring systems, LED-based illumination, and vertically arranged production units. This cultivation method is increasingly central to smart farming strategies, urban food systems, and sustainable agricultural practices. Countries with the most advanced commercial hydroponic sectors include the Netherlands, Japan, Israel, and the United States. Hydroponics has also attracted attention in aerospace research, particularly for growing plants under microgravity conditions. For many years, NASA has carried out extensive studies within its Controlled Ecological Life Support System (CELSS), investigating hydroponics as a potential bioregenerative technology that could support long-term human missions in space (Abeer et al., 2025).

Nowadays, there are several hydroponic techniques, each with multiple variations. Some of them include (Rajaseger, 2023): nutrient film technique (NFT); static solution culture; continuous-flow solution culture; aeroponics; fogponics; passive hydroponics (the Kratky method); Ebb and Flow (flood and drain); the Bengal technique; deep water culture (DWC).

The objective of this paper is to analyze advantages and limitations of hydroponics growing systems and to present a small hydroponic system through a practical case study, with a specific focus on the importance of space setup and equipment in establishing this form of plant production. The general aim to is to contribute to the popularization of hydroponics as a sustainable system of growing plants.

ADVANTAGES AND LIMITATIONS OF HYDROPONIC

Hydroponics has become an essential component of modern agriculture, particularly within the framework of smart farming. This approach provides notable advantages and helps overcome many challenges associated with traditional cultivation practices. Compared to soil-based and even greenhouse production methods, hydroponic systems offer several significant improvements. Efficient use of resources such as water, nutrients, and growing area is one of the major advantages of hydroponic cultivation. Studies (Jones Jr, 2014; Khan, 2018; Rajendran, 2024) show that hydroponic systems can cut water consumption by as much as 90% compared to traditional soil agriculture. Moreover, nutrient solutions can be collected, refreshed, and reused, which supports sustainability and significantly lowers overall waste. When combined with vertical farming approaches, hydroponics also maximizes spatial efficiency, enabling the production of a large number of plants within a relatively small footprint. Hydroponic systems make it possible to grow plants continuously throughout the year, independent of weather patterns or seasonal limitations. Within controlled environments, growers can fine-tune key growth factors such as temperature, humidity, light levels, and nutrient composition. This ensures a steady and reliable food supply, reduces dependence on imports, and strengthens overall food security. Studies (Yee Sin et al., 2023) indicate that hydroponics supports faster plant development and higher yields compared to conventional soil-based farming due to precisely managed growth conditions. Tailoring nutrient solutions and optimizing the root-zone environment significantly enhances plant vigor and overall productivity. Using hydroponics helps lessen the environmental pressures commonly associated with traditional agriculture. Since soil is not required, problems like erosion, nutrient depletion, and soil degradation are minimized. When combined with sustainable practices such as organic pest management, water recycling, and renewable energy hydroponics provides an eco-friendlier and resource-efficient farming approach (Velazquez-Gonzalez et al., 2022). Regarding nutritional quality and flavour, it has been confirmed that precise control of nutrient levels and growing conditions in hydroponic cultivation realize positive effects. Hydroponics creates a growing system that does not rely on soil, which significantly lowers the likelihood of pests and diseases typically transmitted through soil. In such controlled conditions, Integrated Pest Management (IPM) strategies can be applied more efficiently, making greater use of biological control agents and reducing dependence on chemical pesticides. As a result, plants remain healthier and the final produce is safer for consumption. (Handayani et al., 2023). Researchers (Taylor et al., 2012; Ghimire et al., 2023) emphasize relation between hydroponics and urban agriculture due to it allows food production in confined spaces such as rooftops, vertical farms or indoor facilities. Further, local food production positively affects reducing transportation distances, freshness of food and strengthening the local community as well as local involvement and knowledge about sustainable food systems. One more aspect of hydroponics relates to scientific and research importance. It could be a platform for scientific research and innovation in agriculture and space for new techniques investigation, cultivars improving and contemporary approaches for sustainable food production testing. Hydroponic offers possibilities for integrating smart technologies, automation and data analytics contributing to agricultural sustainability and modernization (Monisha et al., 2023).

Although hydroponics offers increased efficiency, sustainability and productivity, overcoming the limitations of traditional agricultural methods, there are some limitations and challenges in regard to pest and diseases control, skill and knowledge, higher set up cost, hot weather and limited oxygenation, sensitivity of plants to even the smallest changes in the growing environment (Pandey et al., 2009). Regarding to pests and disease, situation is contradictory. Soil-borne pests and diseases are largely eliminated in hydroponic crop production, However, these systems introduce other types of risks. In particular, water-borne pathogens may pose a concern, including organisms that represent significant biosecurity threats, such as *Phytophthora* spp. or bacteria harmful to human health. These hazards are especially pronounced in recirculating systems, where pathogens can accumulate over time, making strict sanitation practices essential. Such measures include routine monitoring and treatment of irrigation water. In protected cropping environments, pest pressure may increase because conditions that favor plant growth can also support insect reproduction. This challenge can be managed through well-designed and proactive integrated pest management (IPM) programs. Additionally, the warm and humid conditions typical of covered systems may promote certain fungal diseases, highlighting the need for timely detection and appropriately scheduled control measures (Wootton-Beard, 2019). The primary limitations, however, to the adoption of hydroponic systems are the high initial capital investment and the technical expertise required to manage and operate control systems. Unlike soil-based cultivation, which is relatively tolerant of imprecision and minor errors, hydroponic production relies on highly accurate control of growing conditions, where even small mistakes can lead to significant losses. While enhanced control improves efficiency and productivity, it also introduces a higher level of operational risk. Support and guidance are increasingly available through various organizations, and training opportunities are becoming more accessible. The financial costs of hydroponic systems rise with increasing levels of precision, and the most economically viable technique and scale will vary depending on the crop being grown. Given the wide range of equipment and system designs available, the final choice of a hydroponic system ultimately rests on the individual preferences and objectives of the grower (Kumar et al., 2023).

CASE OF STUDY

Modern agricultural production necessarily requires new and innovative approaches and methods in order to respond to the challenges and demands of sustainable development. A key objective is the production of sufficient quantities of safe and healthy food, while minimizing environmental risks and ensuring economic viability. Official data on the implementation of so-called “green innovations” at farm level indicate that domestic agricultural producers are reluctant to engage in such “experimental” practices. Furthermore, various studies have shown that rural populations, as well as other target groups interested in agricultural production, often lack adequate and relevant information and knowledge about many methods and techniques that align with current sectoral trends and the requirements of the modern market (such as organic and regenerative agriculture, the circular economy, precision agriculture, hydroponics, agroforestry, and aquaculture).

In addition to the general aim of systematizing key information on hydroponics as one of the “green” innovations in agriculture and providing an overview of the status of this method both regionally and globally, this publication through a dedicated section focused on a case study and a detailed analysis of the organization of a hydroponic system in a small-scale setting pursues the following specific objectives: to introduce this method to individuals; to clearly and simply present its critical points; to propose solutions for overcoming these challenges and to stimulate producers' interest in expanding the use of hydroponics in practice, initially through simpler systems and subsequently through their upgrading and further development.

Figure 1. Explained hydroponic growing system (Own source)

All of observations are based on the pilot project realized in small scale hydroponic growing system (Figure 1). Special attention, in the analysis of this pilot project, is given to the importance of space and equipment for organizing hydroponic plant cultivation in small-scale systems.

Preparation and Equipment of the Facility

For the installation of the hydroponic tent in this case, a cabinet designed to accommodate four hydroponic containers a basement space with a total area of slightly over 6 m² was selected. Thorough cleaning and disinfection of the facility were considered essential, as the presence of pathogens (fungi, mold) could endarger the entire project. Disinsection of the basement was also mandatory while it might not be strictly necessary in some other scenarios, it was nevertheless a prudent preventive measure. The basement housed a substation of the district heating system, which proved to be a significant advantage under winter conditions, as no additional heating of the space was required. During the coldest part of the night, when the heating system was not operating, the temperature in the facility did not fall below 16°C, while during the day it did not exceed 27°C.

However, at certain times this upper temperature limit posed a challenge, as there was a risk that temperatures inside the hydroponic cabinet could be even higher. This issue was addressed by improving ventilation within space.

A smart device, a thermometer and hygrometer were installed in the space and connected to an Android application. The device controlled the ventilation fans and issued alerts whenever temperature or humidity deviated from the desired range. The fans were also linked to the same Android application (Figure 2) via a smart device, in this case a smart switch, allowing ventilation schedules and operating durations to be set according to assessed needs. These applications typically provide hourly, daily and monthly reports, thereby offering full flexibility in decision-making.

Figure 2. Android app to control Smart thermometer and hygrometer (own source)

Preparation for the Growing Space (Chamber)

In this case, the “growing space” was in fact a hydroponic cabinet (chamber) measuring 120 cm in width, 120 cm in height and 60 cm in depth. The frame was constructed from wooden slats with a cross-section of 2 × 2 cm. Insulation made of polystyrene was installed in the spaces between the slats, and a thicker plastic film was applied over the entire structure, on both sides of each panel, to prevent moisture penetration into the panels and to ensure better sealing, thereby facilitating more precise control of the growing conditions. The front panel consisted of doors that could be opened across the full height and width, allowing easier access to the growing area. Prior to construction, the cabinet was designed using a 3D modeling program to enable accurate and efficient fabrication (Figure 3).

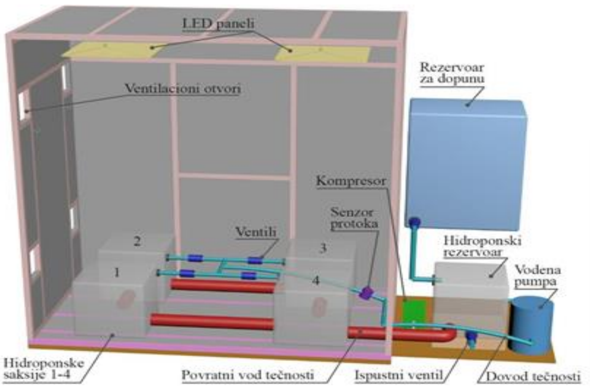

Figure 3. 3D scheme of hydroponic cabinet (Own sorce)

Under different circumstances, it would have been much simpler to use a ready-made grow box or tent designed for plant cultivation; however, in this particular case, this was not an option due to the limited dimensions of the available space.

Equipping the Growing Space

The hydroponic cabinet needed to be equipped with lighting, ventilation, a humidity control system and a system for oxygenating the hydroponic solution. In the case of greenhouses or glasshouses operating year-round, additional heating systems must also be considered, and it is advisable to include a system for regulating carbon dioxide (CO_2) levels. Many authors wrote about importance of climate control, emphasizing it is essential to maintain the proper temperature, humidity, light and ventilation levels within the hydroponic system to ensure optimal growth (Cherif et al., 2023; Santosh and Gaikwad, 2023).

In this case, plant lighting was provided by two full-spectrum LED panels (Figure 4), each with a power rating of 50 W, which proved to be fully adequate for the dimensions of the cabinet. The LED panels were connected to a smart switch that controlled their operation via an application timer, switching them on and off at predetermined times and thereby ensuring 16 hours of "day" and 8 hours of "night."

A challenge encountered in this setup was heat generation from the LED panels, which affected the internal temperature of the cabinet. This required certain modifications to the original plan: the number of ventilation fans, each with a diameter of 12 cm, was increased from four to eight, providing sufficient airflow and enabling proper temperature control.

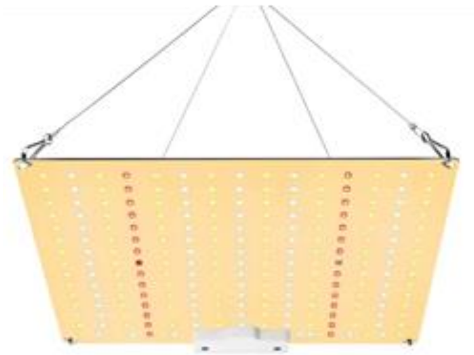

Figure 4. Led panel (https://hidroponika.co.rs/proizvod/led-grow-panel-30x30-50w-uv-ir/)

On the inside, the pages were lined reflective aluminum foil in order to let in as much light as possible bounced off and reached the lower parts of the plants. These factors raise the question of energy efficiency of the system. The previous results have pointed out importance of the novel Integrated Hydroponic Greenhouse Model (IBGH) emphasizing that the consideration of lighting heat plays a pivotal role in achieving energy-efficient heating and cooling processes. The findings suggest, further, that an elliptical structure and PVC as a covering material offer practical advantages (Hassine et al., 2024).

Moisture regulation has proven to be a critical point, especially in small closed and well-sealed rooms like our closet. At the initial stage, when plants are still small, it is desirable for relative humidity (RH) to be in the range of 70-85%, with an optimum of approximately 75%. However, as plants grow, excessive humidity promotes fungal development and plant deterioration; therefore, RH should be maintained at a maximum of about 35-40%. In this case, opening the cabinet doors was not a suitable solution, as each ventilation of the facility (basement) would expose the plants to cold air and cause thermal shock.

The solution was the use of a cabi”et d’humidifier that was not a smart device but was equipped with its own temperature and humidity sensors. The unit automatically activated dehumidification and included a relay switch option, allowing a heater or a fan to be connected for temperature adjustment. The dehumidifier had a dedicated drain for the collected liquid, which was discharged outside the cabinet.

Application of the method additional heating, when it is necessary, depends on the climate and construction of the greenhouse or greenhouse and can be: on solid fuel, with heat distribution; passive solar heating; double wall of the greenhouse made of nylon foil into which warm water is pumped air, heated in various ways, in combination with passive solar by heating; insulating blanket, in combination with passive solar heating, which is developed between the double nylon walls of the greenhouse and geothermal heat pumps - the so-called earth pumps

It Is recommended to control the amount of carbon dioxide (CO_2), in any closed greenhouse or hydroponic room, during daylight hours, because the increased percentage has a favorable effect on the growth and development of plants. Despite this, the idea of controlling the carbon dioxide content in this project was abandoned because it was not possible to meet the required level of precision. The possibility to “make” some amount of CO_2, in such cases, is either in the chemical reaction of vinegar and of baking soda or by using sugar mixture, yeast, baking soda and warm water, without vinegar and electric valve. Practically, these methods were tested in this case, with positive results in CO_2 obtaining (Figure 5).

The difficulties with these methods in such small spaces are due to the fact that CO_2 is heavier than air, so for an even distribution within the space, a larger number of fans is needed, for which these spaces are too limited. This factor requests further and detailed investigation due to its contradictory roles in hydroponics growing system. Although the results demonstrate that CO_2 supplementation significantly enhances the growth of leafy greens grown in hydroponic systems, CO_2 enrichment, however, may also affect produce quality, as indicated by lighter leaf coloration and the occurrence of physiological disorders (Singh et al., 2020).

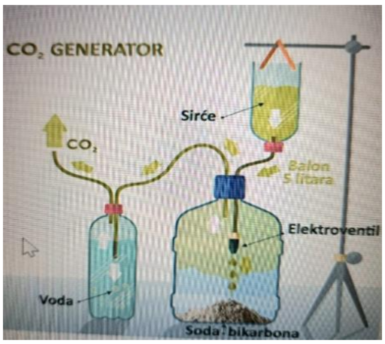

Figure 5. Carbon dioxide generator (Own source)

CONCLUSION

This study confirms hydroponics as an important and sustainable production system that enables efficient use of water, nutrients and space, while allowing year-round crop cultivation under controlled conditions. The case study demonstrated that even small-scale, simplified hydroponic systems can achieve stable plant growth and satisfactory biomass production, provided that critical parameters such as pH, electrical conductivity, temperature, humidity and light are continuously monitored and precisely managed. However, the results also highlight key limitations, including high system sensitivity to minor deviations in environmental and nutrient conditions, technical complexity and the need for adequate knowledge and equipment. Overall, hydroponics represents a promising climate-smart agricultural approach, but its successful application, especially at small scale requires careful system design, constant control and gradual adoption to minimize risks and ensure produce quality.

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