Original Research Article

COMPARATIVE ANALYSIS OF AQUAPONIC, HYDROPONIC, AND GEOPONIC SYSTEMS FOR GREENHOUSE CULTIVATION OF *VIGNA RADIATA* AND *CENTELLA ASIATICA*

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Abstract : Aquaponics is a technology within the integrated agri-aquaculture systems discipline that combines animal and plant culture to optimize resource conservation, nutrient cycling, and overall efficiency. This study compares plant growth across three cultivation methods of hydroponics, aquaponics, and soil-based (geoponics)over a 45-day period, focusing on *Vigna radiata* (Green Gram) and *Centella asiatica* (Gotu Kola). The primary objective was to assess whether water-based systems (hydroponics and aquaponics) promote greater plant height and leaf development compared to traditional soil cultivation. The results revealed that hydroponic systems achieved the most rapid growth, with green gram reaching 18 cm by the end of the experiment. Aquaponics also exhibited improved growth over the soil system, reaching a final height of 14 cm. Soil cultivation resulted in the slowest growth, with green gram attaining 13.7 cm by the end of the study. For Gotu kola, hydroponics showed the fastest growth, with rapid increases after day 5, while aquaponics followed a similar pattern with slightly slower rates. The soil system exhibited gradual growth, with a noticeable increase between days 19 and 25. These findings underscore the benefits of water-based cultivation methods, particularly hydroponics, in promoting faster and more efficient plant growth. The study emphasizes the importance of nutrient availability and water management in optimizing plant development and suggests the potential of hydroponics and aquaponics for enhancing agricultural productivity.

Keywords: Hydroponics; Aquaponics; Geoponics; *Vigna radiate; Centella asiatica*; Water management; Sustainable agriculture.

Citation

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Introduction

In recent years, sustainable agricultural practices have gained prominence as global populations rise and the need for efficient resource management becomes critical. Aquaponics, hydroponics, and geoponics represent three distinct approaches to cultivation that offer varying advantages in terms of growth rates, nutrient efficiency, and resource use. Aquaponics integrates aquaculture with hydroponic crop production, creating a symbiotic environment where fish waste provides nutrients for plants, which in turn purify the water for aquatic species [1]. Hydroponics, on the other hand, involves the soilless cultivation of plants in a nutrient-rich solution, allowing precise control over nutrient delivery and maximizing plant growth [2]. Geoponics, or traditional soil-based agriculture, remains the most widely practiced cultivation method, though its resource demands and environmental impact are more substantial [3]. This study seeks to compare these three systems in the context of greenhouse cultivation. Greenhouses offer a controlled environment that can optimize the conditions for crop growth, making them an ideal setting for comparing aquaponic, hydroponic, and geoponic methods. By providing consistent temperature, humidity, and light exposure, greenhouses minimize the influence of external environmental factors, allowing researchers to focus on the specific effects of each cultivation system [4]. Previous studies have shown that hydroponic systems can outperform geoponic systems in terms of plant growth, nutrient uptake, and water use efficiency [5]. However, less research has been conducted comparing aquaponics to both hydroponics and geoponics, particularly in the greenhouse context.

This study focuses on the cultivation of Vigna radiata (green gram) and Centella asiatica (Gotu Kola), two important crops with different nutritional profiles and growth requirements. Green gram is a legume widely used in South Asian cuisine, valued for its high protein content and nitrogen-fixing properties [6]. Gotu Kola, a perennial herb, is known for its medicinal properties and is used in traditional medicine systems such as Ayurveda and Traditional Chinese Medicine [7]. Both crops are suited to greenhouse cultivation, and their distinct growth patterns make them ideal candidates for comparing different cultivation systems.

The key aim of this study is to evaluate and compare the growth performance of Vigna radiata (Green Gram) and Centella asiatica (Gotu Kola) in aquaponic, hydroponic, and geoponic systems. Growth metrics, such as plant height, biomass, and root development, will be used to assess the effectiveness of each system. The nutrient solutions used in hydroponic and aquaponic systems, as well as the nutrient availability in geoponic soil, will be closely monitored to understand their influence on plant growth [8]. Additionally, this study will examine the potential advantages of circulating and non-circulating culture methods within hydroponic and aquaponic systems.

By comparing these cultivation methods, this study aims to provide insights into the optimal growing conditions for greenhouse crops, with a focus on sustainability and resource efficiency. The results could have significant implications for both small-scale farmers and commercial growers looking to adopt more sustainable agricultural practices. Understanding the comparative advantages of aquaponics, hydroponics, and geoponics can help guide decisions on the most suitable system for different crop types and growing environments [9].

Materials and Methods

Study Area : The experiment was conducted in the Department of Biotechnology at Vivekanandha College of Arts and Sciences for Women (Autonomous), Tiruchengode, Namakkal District, Tamil Nadu. The cultivation systems used included aquaponics, hydroponics, and geoponics. Aquaponics and hydroponics systems were implemented with limited water availability, making them ideal for areas where water conservation is crucial.

Site Selection : The site selection was based on the suitability of aquaponics, hydroponics, and geoponics systems in environments with restricted water availability for the removal of fish waste in aquaponics [8]. The study involved circulating and non-circulating systems for comparison of plant growth between aquaponics and hydroponics, while geoponics was used as the control.

Selection of Plants : Vigna radiata (Green Gram) and Centella asiatica (Gotu Kola) were selected for their rapid germination rates, making them ideal for the experiment. These crops were chosen to facilitate easy replication of the experiment by others interested in comparing hydroponic and soil-based plant growth [6].

Selection of Fish : For the aquaponic system, Poeciliasphenops (molly fish) were selected to provide the necessary nutrient cycle for plant growth [9].

Aquaponics Culture Method (Circulating System) : Aquaponics employed a circulating system where materials like gravel and coconut fiber were used to support plant roots. After germination, seeds were transferred to trays placed in a rack equipped to collect and reuse drained nutrients. Each plant received 20 ml of nutrient solution daily, with pH and electrical conductivity (EC) maintained at 6.5 and 1500 µS/cm, respectively. Plant height was measured daily [1].

Hydroponics Culture Method (Non-Circulating System) : The hydroponics system utilized a non-circulating method in which plant roots were immersed in nutrient solution. Glass cups measuring 10 cm in width and 15 cm in height were used, with net pots placed on ridgiform plates. Nutrient solution was filled up to 10 cm, leaving a 5 cm gap between the solution and the plate. The pH and EC were maintained at 6.5 and 1500 µS/cm, respectively, and were adjusted weekly [10]. Plant height was measured daily.

Geoponic System (Control) : In the soil culture control, seeds were directly sown into trays filled with soil. This traditional method provided a benchmark for comparison with aquaponic and hydroponic systems. After germination, plant height was measured daily over a 45-day period.

Setup for Side-by-Side Comparison : The growing zone in the greenhouse was set up to facilitate a side-by-side comparison of aquaponics, hydroponics, and soil-based systems. For aquaponics, trays were filled with coco peat, and plants were irrigated with nutrient solution daily. In the hydroponics system, nutrient solutions were managed carefully, ensuring the proper balance of macro and micro-nutrients [2]. For the soil system, seeds were sown directly into soil-filled trays, and the experiment was maintained for 45 days.

Nutrient Solution for Hydroponics: The hydroponic system used a nutrient solution containing essential macro- and micro-nutrients, including nitrogen, phosphorus, and potassium (NPK). These nutrients were supplied through formulations prepared from water-soluble fertilizer salts [2]. Organic nutrient sources, such as banana peel water, tea powder water, and egg shell water, were also incorporated to provide additional minerals and vitamins like phosphorus, calcium, magnesium, and vitamin C [10].

Results

In this study, the growth of plants was monitored over a 45-day period using three different cultivation methods: aquaponics, hydroponics (water culture), and soil-based (geoponics) systems (Figure 1). The study aimed to assess whether plants would grow taller and develop more leaves in aquaponic and hydroponic systems compared to traditional soil cultivation.

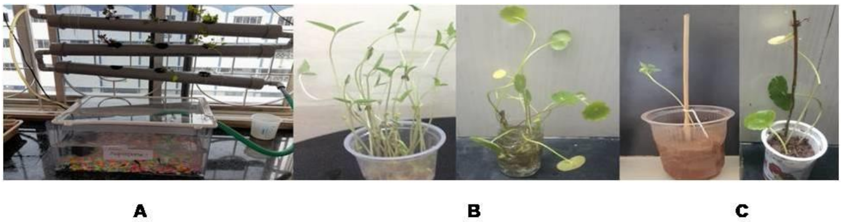

Fig 1: Aquaponics Culture Method (A), Hydroponics Culture Method (B), Geoponic System (C).

The results, presented in figures and 3, demonstrated that plants grown using water culture and aquaponics methods exhibited the greatest height. Specifically, both Vigna radiata(green gram) and Centella asiatica(Gotu kola) reached their maximum average height in the water-based systems at the end of the experiment, surpassing the growth observed in soil-based cultivation.

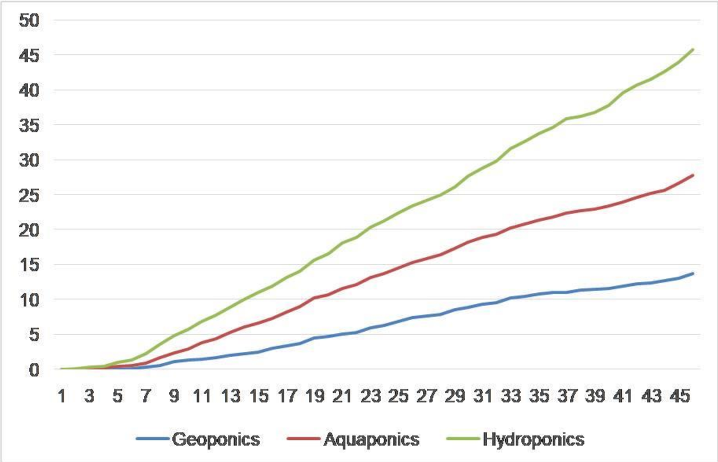

Fig 2: Plant Growth in hydroponics, aquaponics and geoponics in *Vigna radiate*

Figure 2 illustrates the growth comparison of Vigna radiata across hydroponics, aquaponics, and soil (geoponics) systems over a 45-day period, revealing notable differences in growth rates and final plant heights. Hydroponics demonstrated the fastest growth, reaching 18 cm by the experiment's end, significantly surpassing the other systems. Aquaponics achieved a final height of 14 cm, showing a more rapid growth rate compared to the soil system, particularly after the first week. In contrast, the soil system displayed a slower, steady growth, with a final height of 13.7 cm. These findings highlight hydroponics as the most effective method for promoting plant growth, while aquaponics provided a moderate advantage over soil, underscoring the crucial role of nutrient availability and water management in enhancing plant development.

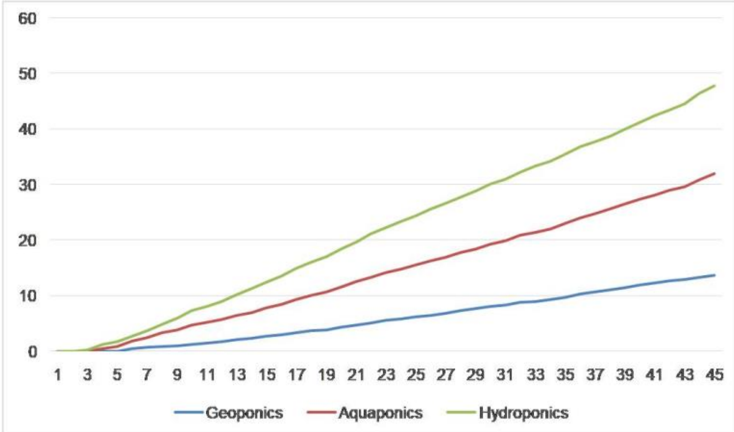

Fig 3: Plant Growth in hydroponics, aquaponics and geoponics for and Centella asiatica

Figure 3 presents the growth patterns of Centella asiatica in different systems over 45 days. In the soil (geoponics) system, plant height increases gradually, with a distinct surge in growth between days 19 and 25. In contrast, the hydroponics system displays a more consistent growth trajectory, marked by a rapid increase in height after day 5, leading to faster growth compared to the soil system. Similarly, the aquaponics system shows steady growth beginning on day 6, maintaining a consistent upward trend throughout, ultimately surpassing hydroponics in the later stages. Both hydroponics and aquaponics demonstrate faster growth than the soil system, with aquaponics slightly outperforming hydroponics toward the end of the observation period.

Discussion

The comparative analysis of plant growth across three different cultivation systems of hydroponics, aquaponics, and soil-based (geoponics)over a 45-day period revealed significant differences in plant development for both Vigna radiata(green gram) and Centella asiatica(Gotu kola). The study aimed to evaluate whether the water-based systems, aquaponics and hydroponics, would promote more rapid growth and yield higher final plant heights compared to traditional soil cultivation.

The results demonstrated that both aquaponics and hydroponics fostered greater growth rates and final heights compared to soil-based cultivation, particularly for green gram. Plants grown in hydroponic systems exhibited the most rapid growth, with the green gram reaching a final height of 18 cm by the end of the experiment. This surpasses the height achieved by the same species in the aquaponic system, which reached 14 cm, and the soil-based system, where plants reached 13.7 cm. The superiority of the hydroponics system is attributed to its optimized nutrient availability and continuous water flow, which ensures that plants have access to essential nutrients in an ideal concentration. Previous studies support these findings, as hydroponic systems have been shown to promote faster growth rates due to the absence of soil-borne pathogens and improved control over the root environment [11,2].

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Aquaponics also demonstrated enhanced plant growth compared to soil cultivation, albeit to a slightly lesser degree than hydroponics. The final height of green gram plants grown in aquaponics reached 14 cm, a slight improvement over the soil system. Aquaponics combines hydroponics with aquaculture, and while nutrient supply is somewhat dependent on the fish system, it still offers superior growth conditions over soil. The gradual but steady growth in the aquaponics system aligns with previous research, which highlights its benefits in terms of sustainable nutrient recycling [8]. Although aquaponics showed slower growth initially compared to hydroponics, it still outperformed traditional soil methods, emphasizing its potential as a balanced and sustainable alternative.

For Gotu kola, the results were consistent with those observed for green gram, though the growth patterns varied slightly. The hydroponic system resulted in the most rapid growth, with noticeable acceleration after day 5, leading to the tallest plants at the end of the experiment. Aquaponics followed a similar pattern, with steady growth beginning around day 6 and continuing throughout the experiment, achieving slightly lower final heights compared to hydroponics. The soil system exhibited the slowest growth, with a period of more rapid height increase between days 19 and 25, although it still lagged behind the water-based systems in terms of overall plant development.

The differences observed between the soil and water-based systems can be attributed to the distinct nutrient dynamics and water management practices inherent to each method. Soil-based systems often suffer from limitations related to nutrient availability, water retention, and root zone aeration, factors that can constrain plant growth [12]. Conversely, both hydroponics and aquaponics ensure a consistent and controlled nutrient supply directly to plant roots, promoting optimal conditions for growth. The consistent and rapid growth observed in the hydroponic system, in particular, underscores the importance of precise nutrient management and water delivery in enhancing plant performance [13].

The results of this study highlight the effectiveness of water-based systemsparticularly hydroponicsfor optimizing plant growth. Hydroponics demonstrated the most rapid and substantial growth across both species, followed by aquaponics, which also outperformed the traditional soil-based method. These findings reinforce the potential of hydroponic and aquaponic systems for improving agricultural productivity, especially in environments where soil quality or water availability may be limiting factors. As food security becomes an increasingly critical issue, these systems offer promising solutions for enhancing plant growth and yield in a sustainable manner [1]. Further research should explore the long-term impacts of these systems on plant health and yield, as well as their potential scalability for commercial agricultural use.

Conclusion

This study demonstrates that water-based cultivation systems, particularly hydroponics, significantly outperform traditional soil-based methods in promoting plant growth. Both Vigna radiata(green gram) and Centella asiatica(Gotu kola)exhibited faster growth and reached greater final heights in hydroponic and aquaponic systems compared to geoponics. Hydroponics proved to be the most effective system, offering optimal conditions for nutrient uptake and water management, resulting in the highest growth rates. Aquaponics also showed enhanced growth, though slightly less than hydroponics, yet still superior to soil cultivation. These findings highlight the potential of hydroponic and aquaponic systems for improving agricultural efficiency and sustainability, particularly in environments with limited soil fertility or water resources. Further research is recommended to explore the long-term benefits and scalability of these methods for broader agricultural applications.

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