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Vegetable production through aquaponics: A prospective of future crop production

Sandeep Indurthi, Ira Sarma and Chereddy Maheswarareddy

Sandeep Indurthi
Department of Horticulture,
Assam Agricultural University,
Jorhat, Assam, India

Ira Sarma
Department of Horticulture,
Assam Agricultural University,
Jorhat, Assam, India

Chereddy Maheswarareddy
Department of Agronomy, Assam
Agricultural University, Jorhat,
Assam, India

Corresponding Author:
Sandeep Indurthi
Department of Horticulture,
Assam Agricultural University,
Jorhat, Assam, India

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Abstract

Hydroponics and aquaponics are innovative agricultural methodologies that offer a range of environmental solutions. It is expected that the use of hydroponic systems would yield a more substantial financial gain through the sale of vegetables and other botanical specimens. One of the ways for vegetable and other crop cultivation involves the utilization of an inert medium, such as sand, perlite, gravel, rock wool, peat moss, vermiculite, coir, or sawdust, to offer mechanical support. One particular form of soilless cultivation is referred to as "hydroponics," which has been found to consume a reduced amount of water compared to conventional growth methods. The increasing popularity of hydroponic agriculture on a global scale can be attributed to its efficient management. The fundamental components of this technology encompass enhanced productivity, safety measures, and efficient water resource management. Furthermore, the discussion has encompassed the prospective areas of future investigation in the fields of hydroponics and aquaponics. Moreover, this study aims to identify and examine the diverse uses of hydroponics and aquaponics within the field of agriculture.

Keywords: Fish, growing media, hydroponics, soilless, vermiculture and water

Introduction

Innovative farming methods are essential for combating climate-related crop production challenges. Changing growing mediums can sustainably feed the growing population while conserving water and land. Ensuring food security requires accessible resources. Water scarcity limits agricultural output, worsening hunger. Adopting agricultural technology can conserve water and boost food accessibility and productivity, crucial for global sustenance. The science of growing plants without soil is known as hydroponics (Savvas, 2003) [43]. Hydroponic farming has been found to enhance both the quality and production of crops, hence contributing to increased economic output and competitiveness. Hydroponics is an agricultural technique that involves cultivating plants in nutrient solutions, which consist of water infused with fertilizers (Sharma *et al.*, 2018) [45]. Most hydroponic systems are designed to operate autonomously, effectively managing the supply of water, nutrients, and photoperiod in response to the specific requirements of different plant species (Resh, 2013) [39]. Green vegetables, tomatoes, cucumbers, peppers, strawberries, and a variety of other specialized and commercial crops can potentially be grown with hydroponics. The France, Netherlands, and Spain are the top three European producers of hydroponics, followed by USA and the Asian-Pacific countries (Prakash *et al.*, 2020) [35].

Increasing world population and shrinking cultivable areas are the challenging issues for global food security (Tilman *et al.*, 2011) [48]. Some other threats related to adverse environmental conditions and climate change also pose problems for food grain and livestock production across the world (Nobre *et al.*, 2010) [34]. Therefore, the creation of an alternative system of grains, vegetables and food production using limited resources may provide strength to global food security (Edwards, 1993) [12].

In the context of global hunger, Aquaponics is a sustainable approach to produce food that employs a biomimetic natural system and circular economy principles to reduce input and waste. It is a resourceful mechanism that integrates ideally with the expansion of intensive farming in a sustainable way (Joly *et al.*, 2015; Vermeulen and Kamstra, 2012; Tyson *et al.*, 2011) [25, 52, 49].

It facilitates the soilless production of vegetables and some minor fruits. Aquaponics is a wonderful technique that requires limited resources (Effendi *et al*., 2015) [13]. The aquaponics system has garnered significant interest as it possesses the ability to efficiently rear fish in dense populations, maintain optimal water quality, reduce the need for frequent water replacement, and yield profitable vegetables that directly utilize dissolved fish waste and byproducts of microbial decomposition (Chopin *et al*., 2008) [8]. The establishment of an optimal aquaponics system necessitates adherence to specific water chemistry prerequisites, as the attainment of ideal water quality is imperative for the maintenance of a robust, harmonious, and operational system (Goddek *et al*., 2015) [19]. Moreover, nutrient and energy balance analysis is the basic criteria for the creation of an ideal aquaponics system. In contrast to conventional agricultural practices, aquaponics demonstrates remarkable efficacy in terms of water and nutrient utilization, as well as yield per unit area, while minimizing the release of pollutants (Bunting and Shpigel, 2009) [5]. Aquaponics system offers agriculture production in controlled environmental conditions under the deserts, tropical, temperate and sub-tropical regions across the world (Jensen, 2001) [24]. Furthermore, aquaponics also facilitates food production and water conservation as one of the ideal models in desert countries like Saudi Arabia. Aquaponics is a system that combines aquaculture and hydroponics in a mutually beneficial relationship, effectively addressing concerns related to resources and the environment (Mcmurtry *et al*., 1997) [32]. In aquaponics, most of the waste generated by the fish is utilized by the plants under aquaponics system as plant nutrients (Seawright *et al*., 1998) [44]. However, aquaponics system is an alternative form of organic farming that can be appreciated by the people associated with food production employing aquaponics (Gelfand *et al*., 2003; Rakocy *et al*., 2003) [36]. The benefits of furthering aquaponics research and subsequent fish and vegetable cultivation, which provides an alternative to current monoculture, include balanced use of water, nutrients, and fertilizer. Aquaculture is one of the suitable systems useful for large and small-scale food production (FAO, United Nations, 2014) [17].

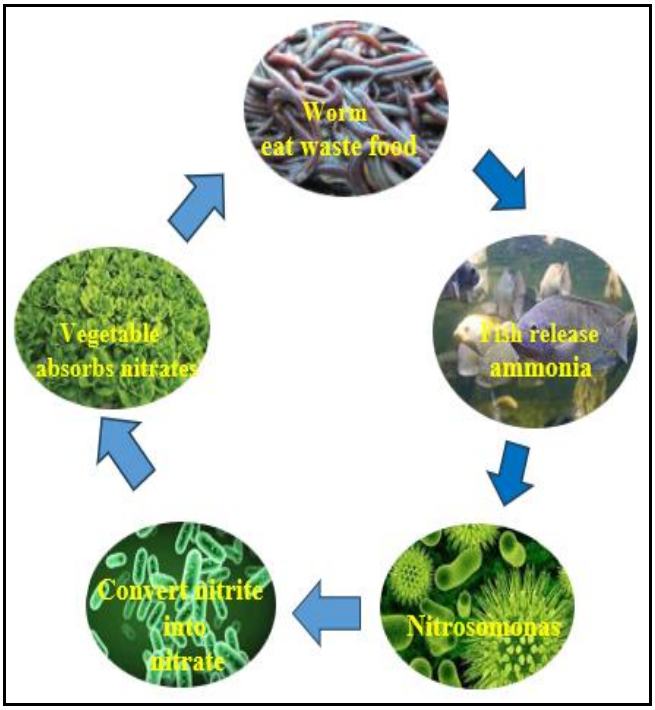

Fig 1: Procedure of aquaponics for vegetable production

Growing media used in hydroponics

The hydroponic technique of vegetable production needs both organic and inorganic media. The major ingredients of the organic and inorganic media used in hydroponic-assisted vegetable production is summarized in the literature.

Organic growing media: The organic media used in hydroponic production includes coco peat, rice hull, saw dust as major components for the soil-less production of leafy and other vegetable crops on plant growth (Tzortzakis & Economakis, 2008; Maboko *et al*., 2013) [30, 50].

Coco peat: It is a coconut husk byproduct. Cocopeat can be used for a wide range of applications, such as cutting of propagation plants, nursery growth and development, germination of seeds, hydroponic and greenhouse cultivation techniques (Basirat, 2011) [3]. Numerous soilless crops, including tomato, eggplant, cucumber, and capsicum, are grown using coconut peat with no negative effects on the environment. The high crop load demand and high temperatures can be absorbed by the coco peat's high-water holding capacity without affecting the air supply.

Rice Hull: It's advantageous qualities as a growing medium consist of its low weight, inertness to nutrient adsorption and desorption, good drainage, aeration, and slow rate of decomposition (Saparamadu, 2008) [42]. According to Bradly and Marulanda (2000) [4], combining rice hull with substances like coal scoria, sawdust, river sand, and volcanic scoria can effectively serve as a medium in simplified hydroponic setups. However, in media supplemented with rice hulls, N depletion is not a significant issue. Rice hulls might be utilized if they are available. Despite their organic nature, these materials exhibit a moderate rate of decomposition, similar to coco coir. This characteristic renders them suitable for use as a hydroponic growing medium. There exist four distinct categories of rice hulls, namely fresh, aged, composting parboiled, and carbonized. The utilization of fresh rice hulls in hydroponic systems is not recommended.

Inorganic growing media: Inorganic media includes perlite, sand, rock wool, vermiculture, and Oasis cubes enable controlled nutrient delivery due to their chemical neutrality (De Rijck and Schrevens, 1998) [11].

Perlite: It is a volcanic grey-white silicate material with a pH of zero, and when heated quickly to a temperature of roughly 1600-1700° F, it expands four to twenty times its original volume. This expansion results from the 2-6% total water content in the crude perlite rock, which makes the perlite pop like popcorn. Each particle has thousands of small cavities on its surface, giving it a very vast surface area. The roots of plants can access these areas because they help retain moisture and nutrients. Furthermore, because of the physical characteristics of each particle, air passageways are created that offer the best possible aeration and drainage. Its highly versatile medium extensively employed in cultivating various vegetables such as tomatoes (Szmidt *et al*., 1987) [46], peppers, cucumbers (Hochmuth and Hochmuth 2022) [96], melons (Rodriguez *et al*., 2006) [40], lettuce (Frezza *et al*., 2004) [29] and carrots (Asaduzzaman *et al*., 2013) [2].

Sand: In hydroponics, sand is actually a highly popular growing medium. Sand is similar to rock, but smaller. Since the particles are tiny and finer than those in typical rock, there is no potential for moisture to quickly drain. Additionally, Vermiculite, perlite, or coco coir are frequently used with sand. It allows to aerate the root mix and maintain moisture.

Rock wool: Rock wool is generally produced by melting a basalt and limestone mixture at a temperature of 1600 ^{0}C. After being spun quickly into thin fibers with a diameter of 0.005 mm, the molten mass is then treated with glue to bind, the fibers are compressed into slabs of different dimensions. Rock wool slabs are favored for horticultural applications in soilless systems due to several benefits, including ample total pore space and the inert, sterile, and uniform conditions resulting from the material's production process. This facilitates consistent yields throughout the cultivation period (Bussell and McKennie, 2004) [6].

Oasis cubes: Oasis cubes resemble to rock wool cubes in appearance and characteristics. However, oasis cubes resemble the firm green or white floral foam i.e., commonly utilized by florists to hold stems in flower arrangements. The Oasis cubes are defined by their open-cell structure, enabling them to absorb both water and air. Although, oasis cubes and rock wool are similar, but oasis cubes consist of less tendency to become submerged than rock wool cubes.

Vermiculite: Chemically, it is hydrated magnesium aluminum silicate. The product pf vermiculite is generally enlarged, plate-like particles that result from heating vermiculite to about 745 ^{0}C have a high-water holding capacity and aid in drainage and aeration. Expanded vermiculite-based products find extensive applications in commercial settings due to their intricate ion-exchange and sorption properties, which encompass both inorganic and organic cations (Marcos and Rodriguez, 2014) [31]. This microscopic mineral which is a strong source of potassium and magnesium and has good buffering and exchange capabilities. Vermiculite is thought to be lower durability compared to than sand and perlite, but its chemical and physical characteristics make it an excellent choice for container media.

Vegetable production

The cultivation of vegetable crops involves the utilization of Styrofoam rafts that are positioned on the top of hydroponic troughs. The dimensions of the rafts are 2.4 × 1.2 × 3.9 cm, resulting in a total area of 2.97 m2. These rafts were treated for planting purposes through the application of harmless white roof paint, namely Cool-Cote 22-DW-9, manufactured by BLP Mobile Paints in Mobile, AL. Holes with a diameter of 4.8 cm are drilled into the rafts at varying intervals to accommodate the specific needs of different plants. The planting density of various crops and mature plant sizes can vary from 0.67 to 30 plants per square meter. In order to secure the rooted seedling, net pots measuring 5 × 5 cm are placed within each designated hole (Rakocy *et al.*, 2012) [37]. Seedlings are cultivated within a greenhouse structure that is both open-ended and covered. The seedling flats used in this study measure 25.4 × 50.8 cm and include 98 cells, each measuring 2.54 × 2.54 × 2.54 cm. These flats are covered with potting mixture of ProMix®, a commercially available substrate produced by Premier Tech Horticulture located in Rivieredu-loupe, Quebec, Canada. The ProMix® potting mix is composed of a blend of peat moss (79%-87%), perlite (10%-14%), and vermiculite (3%-7%). Based on the specific needs of the seeds, the seeds are either surface-seeded using a vacuum seeder i.e., Seed E-Z Seeder, Inc. Baraboo, WI or manually drilled into 1.5 cm deep holes made in the ProMix® media, depending on the particular requirements of the seeds. The seedling flats are irrigated in order to initiate the process of germination, following which they are then covered for a period of 2-3 days till the emergence of cotyledons. Subsequently, the flats are exposed, enabling the seedlings to undergo a developmental process spanning a duration of around 2 to 3 weeks. The seedlings are subjected to a watering regimen of twice - daily and receive weekly fertilization with Peters Professional Plant Starter 4-45-15, a product manufactured by Everris International B.V. in Warrensburg, The Netherlands. Seedlings are deemed suitable for transplantation when they have produced 1-2 sets of genuine leaves and their roots have sufficiently encircled the growing medium. The individuals are transferred to sterile rafts within the aquaponic system. In order to effectively manage pests, it is necessary to apply Bacillus thuringiensis subsp. kurstaki strain ABTS-351, fermentation solids, spores, and insecticidal toxins (commercially known as Dipel® DF; Valent Biosciences, Libertyville, IL) on a weekly basis to all crops. This treatment is aimed at controlling caterpillars. Additionally, for crops that are prone to infestations of aphids and white flies, the application of insecticidal soap containing potassium salts of fatty acids (marketed as M-Pede; Dow AgroSciences, Indianapolis, IN) is recommended. The plants are cultivated within the system for the necessary duration until they reach maturity (Rakocy *et al.*, 2036) [36].

Aquaponics and Conservation of Water

The economic notion of relative productivity pertains to the assessment of the relative allocation of resources required for the production of a single unit of goods or services. Efficiency is commonly understood to be greater when the demand for resources is reduced per unit of goods and services. Nevertheless, it's essential to consider water quality into an account when considering water usage efficiency in an ecological framework, because of improving the quality of water increases efficiency (Hamdy, 2007) [21]. The issue of lack of water is increasingly pressing, necessitating enhancements in water-use efficiency, particularly in dry areas. In these places, water availability for agricultural purposes and the quality of discharged water plays crucial roles in production of food. In the aforementioned regions, the process of water recirculation within aquaponic systems has demonstrated a notable water re-use efficiency ranging from 95% to 99% (Dalsgaard *et al.*, 2013) [10]. The water requirement for fish collected is found to be below 100 L/kg, and the maintenance of water quality is ensured within the agricultural system for crop production (Goddek *et al.*, 2015) [19]. It is imperative to develop and run these systems in a manner that minimizes water losses. Additionally, it is crucial to optimize the proportions of fish water to plants, as this balance plays a significant role in improving reuse of water productivity and assuring optimal nutrients recycling. There is ongoing development of modelling algorithms and technical solutions aimed at integrating enhancements in specific units and gaining a deeper understanding of how to manage water resources in a more effective and efficient manner (Vilbergsson *et al.*, 2016) [53]. Considering the soil, water, and nutrient needs, it can be observed that aquaponics has a significantly more favorable water footprint compared to conventional agriculture. This is mostly because of the limitations posed by water quality, water demand, and arable land availability, as well as the expenses associated with fertilizers and irrigation, which hinder the spread of traditional agricultural practices.

Aquaponics and Utilization of Land

Aquaponic farming techniques are characterized by their lack of soil and their aim to recycling essential nutrients for fish and plant growth. These systems utilize nutrients derived from organic matter found in fish feed and waste, hence reducing or eliminating the necessity for traditional plant fertilizers (Thomas *et al*., 2017) [47]. In these particular systems, the need for land utilization in activities such as mining, processing, stockpiling, and transporting fertilizers abundant in phosphate or potash is rendered obsolete. Consequently, this elimination of land-related requirements results in the eradication of associated costs, including both the initial expenses and the expenses incurred during the application of these fertilizers (Cripps and Bergheim, 2000) [9]. The practice of aquaponics production not only enhances water consumption efficiency but also improves efficiency of agricultural inputs through the reduction of land requirements for production. Facilities, for example, have the potential to be located on terrain that is not suitable for agriculture and in suburban or metropolitan regions that are in close proximity to markets. This has the advantage of minimizing the carbon emissions linked to rural farms and the transportation of goods to urban markets (Hulata and Simon, 2010) [23]. By having a reduced physical space requirement, it becomes feasible to establish manufacturing facilities in regions that would normally be considered unproductive, such as roofs or abandoned factory sites. This approach may lead to cost savings in terms of land purchase, particularly if these areas are deemed inappropriate for residential or commercial use. The use of aquaponics, a sustainable method for producing vegetables and beneficial proteins, can potentially alleviate the need to remove ecologically significant natural and semi-natural regions for traditional agricultural practices. This is due to the decreased spatial requirements of aquaponics systems, which have the potential to minimize the environmental impact associated with conventional agriculture (Liu *et al*., 2016) [28].

Control of Pests, Weeds and Diseases

Aquaponic systems, characterized by their closed nature and implementation of biosecurity controls, necessitate much-reduced utilization of chemical pesticides in the plant component. By implementing meticulous handling and monitoring practices for seed and transplant stocks, it is possible to effectively control weeds, bacterial, algal and fungal contaminants in hydroponic systems. This approach focuses on employing specific strategies to address these issues, rather than resorting to the broad use of pesticides and fungicides commonly used in traditional soil-based agriculture (Samuel-Fitwi *et al*., 2012) [41]. With the continuous advancement of technology, it is possible to observe additional reductions in pest problems with the implementation of positive-pressure greenhouses (Mears and Both, 2001) [33]. The implementation of design features aimed at mitigating pest risks can result in cost savings in various aspects, such as the reduction of chemical usage, labor requirements, application time, and equipment expenses. This is particularly significant considering the limited land footprint of industrial-scale aquaponics systems, which are characterized by their compact and tightly contained nature. In comparison to conventional soil-based farms cultivating vegetable and fruit crops in open production areas, aquaponics systems offer a more condensed and confined environment. The utilisation of Recirculating Aquaculture Systems (RAS) in aquaponic systems effectively mitigates the risk of disease transmission among cultivated and wild populations. This problem is particularly significant in the context of inflow-through and open-net pen aquaculture (Read *et al*., 2001) [38]. The routine use of antibiotics is typically unnecessary in the RAS component due to its closed nature and limited potential for disease transmission. In addition, the utilization of antimicrobials and anti-parasitic agents is commonly discouraged due to their potential negative impact on the microbiota, which plays a vital role in the conversion of organic and inorganic wastes into chemicals that are beneficial for growth of plants inside the hydroponic system (Junge *et al*., 2017) [26]. The implementation of confinement measures for both fish and plants inside their respective environments enhances the feasibility of decontamination and eradication in the event of disease emergence. While it is evident that closed systems may not entirely eliminate all disease and pest issues (Goddek *et al*., 2015) [19], the implementation of appropriate biocontrol strategies in stand-alone recirculating aquaculture systems (RAS) and hydroponics has proven to significantly mitigate associated risks.

Aquaponics and Energy Conservation

Aquaponic systems are becoming more "energy smart" as technology improves. This means that the carbon debt from pumps, filters, and cooling or heating devices can be reduced by utilizing power made from sources of renewable energy (Goddek and Keesman, 2018; Yogev *et al*., 2016) [20, 54]. In temperate latitudes throughout the evening, numerous contemporary designs have been developed to facilitate the complete reintegration of energy utilized for heating and cooling fish tanks and greenhouses. As a result, these systems no longer necessitate any inputs beyond solar arrays or power (Ezebuiro and Korner, 2017) [14]. Furthermore, aquaponic systems have the potential to employ microbial denitrification as a means of transforming nitrous oxide into nitrogen gas. This process can occur provided there is an adequate supply of carbon sources derived from waste materials. Consequently, bacteria that are heterotrophic or facultatively anaerobic are able to converting surplus $NO3^-$ (nitrates) into N_2 (nitrogen gas) (Van Rijn *et al*., 2006) [51] and N_2O (nitrous oxide) has strong greenhouse gas properties, and the existing microbial population within enclosed aquaponics systems can effectively catalyze its transformation into N_2 (nitrogen gas) (Kloas *et al*., 2015) [27].

Future Prospective of Aquaponics

In the last century, this technology has enabled agricultural output to expand rapidly, supporting enormous population expansion. Nevertheless, these alterations have the potential to compromise the ability of ecosystems to support agricultural productivity, preserve freshwater and forest reserves, and contribute to the regulation of climate patterns & quality of air (Foley *et al*., 2005) [16]. One of the foremost obstacles in the realm of novel food production, particularly in the context of aquaponics, revolves around the need to effectively tackle regulatory concerns that impede the widespread adoption and growth of integrated technologies. Numerous authorities possess control over water, health of animals, safeguarding the environment, and food safety, so resulting in instances when their policies may exhibit contradictions or prove inadequate for intricate linked systems (Joly *et al*., 2015) [25]. Presently, laws and regulations are some of the most perplexing areas for producers and aspiring entrepreneurs. The necessity for growers and investors to have established norms and rules in order to acquire licenses, loans, and tax exemptions is evident. However, the current situation, where regulatory authorities have overlapping roles, underscores the pressing want for more harmonization and clear definitions. Regulatory regimes often present challenges due to their complexity, and the issues surrounding agricultural licensing and consumer certification persist in numerous nations. According to the Food and Agriculture Organization (FAO, 2017) [15] there has been a new initiative to establish uniform regulations for ensuring animal health, welfare, and food safety in aquaponics systems. Additionally, efforts have been made to standardize regulations for the import and export of aquaponic goods.

Conclusion

It is encouraging that the aquaponic system and anaerobic digestion technologies may be combined in a closed system. It has the ability to address current issues with widely utilized methods in aquaponics and developing nations. This technique has the potential to create an off-grid, high-quality, consistently available, and fresh source of protein and vitamins if it is developed into a working agricultural unit. Communities in deserts and other isolated, climate-challenged areas frequently lack an electricity grid and have low grid reliability. These are the areas where aquaponics has the most potential to improve food security and maybe alleviate vitamin and protein deficiencies. However, as shown by the difficulties mentioned in this work, more study and advancements are preferred. These discussions must be focused on establishing fully controlled, standardized aquaponics systems that are manageable and financially viable. Therefore, inadequate monitoring and significant energy costs are the motivating factors for the creation of a smart aquaponics system. Aquaponics has various advantages that extend beyond the effective utilization of land, water, and nutrient resources. It facilitates enhanced integration of intelligent energy solutions, including biogas and solar electricity. Aquaponics is a very promising technological approach that enables the production of superior fish protein and vegetables with reduced land, energy, and water requirements. Moreover, it effectively mitigates the reliance on chemical and fertilizer inputs commonly employed in traditional food production methods.

Competing Interests

Authors have declared that no competing interests exist.

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