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A Comprehensive Review on Soilless Cultivation for Sustainable Agriculture

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This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Review Article

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ABSTRACT

With the growing challenges of food security and environmental degradation, there is an increasing need for sustainable agricultural practices. Soilless cultivation techniques offer a promising solution by minimizing land and water use while maximizing crop yield and quality. This review examines the potential of soilless cultivation methods in promoting sustainable agriculture. The purpose of this review is to evaluate the effectiveness of soilless cultivation techniques in sustainable agriculture. It aims to analyze the various methods used, their advantages and limitations, and their contributions to environmental sustainability and food security. A comprehensive literature review was conducted to gather information on soilless cultivation techniques, including hydroponics, aeroponics, and aquaponics. Relevant studies and reports were analyzed to assess the performance of these methods in terms of resource efficiency, crop productivity, and environmental impact. The review found that soilless cultivation techniques offer significant advantages over traditional soil-based farming, including higher crop yields, efficient water and nutrient use, and reduced environmental footprint. Hydroponic systems, in particular, have been widely adopted and have shown promising results in various crops. Additionally, soilless cultivation methods can be

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tailored to different environmental conditions, making them adaptable to a wide range of settings. In conclusion, soilless cultivation holds great potential for sustainable agriculture by addressing key challenges such as land and water scarcity, soil degradation, and climate change. While further research and technological advancements are needed to optimize these techniques and make them more accessible to farmers, the evidence suggests that soilless cultivation can play a significant role in achieving global food security and environmental sustainability goals.

Keywords: Comprehensive; soil-less cultivation; aeroponics; hydroponics.

1. INTRODUCTION

By 2050, there will be an additional two to three billion people on Earth [1]. Feeding them using standard agricultural methods was found to be unfeasible due to unpredictable conditions and inadequate farm management [2]. Due to high-priority challenges, the management of resource usage needs to be modified to give human food consumption precedence [3]. Irrigation is being increasingly widely used in agricultural activities, which affects soil quality and depletes groundwater supplies. There was less of a food scarcity as a result of the population growth and loss of agricultural land brought on by fast urbanization and industrialization. Soilless farming is a potential answer to these problems. Two techniques for growing plants without soil are hydroponics and aeroponics [4]. Hydroponic and aeroponic crop cultures have been used by many farms all over the world for agricultural production and research. With its considerable advancements over the last half-century, the technology might currently be the most intensive crop production method employed in the contemporary agriculture industry [5]. A soilless culture can provide crops with comparable growth and production to field soil [6]. Soilless agriculture, often known as hydroponics, is a cutting-edge and highly effective approach to enhancing farming practices and maximizing crop production [7]. Hydroponically producing food could be the first move toward a more sustainable lifestyle [8]. By providing the nutrient solution, crops can be grown hydroponically in any type of growing medium [9]. A hydroponics plantation is a contemporary form of agriculture that offers total control over the distribution and delivery of nutrients to the plants. The earliest known example of hydroponics is found on the wall of the over 4,000-year-old Egyptian temple Dier El Bahari [10]. In commercial agriculture, the quantity of land required for crops is reduced by 75% when hydroponics is used. The water and nutrients in the system are efficiently and effectively regulated while maintaining proper environmental control thanks to the application of hydroponics techniques. Commercial crops like green vegetables, tomatoes, cucumbers, peppers, strawberries, and many more can be grown hydroponically [11]. The hydroponics subset known as aeroponics uses fertilizer solutions sprayed on suspended plant roots inside of a container [5]. Aeroponic cultivation is the practice of cultivating plants in a mist environment without the use of soil [4]. Pipes, spray nozzles, a pump, and a timer for misting inside the container make up a system for transferring nutritional solution from a nutrient tank [12]. Aeroponics is a soilless cultivation system that can be used as an alternative technique for growing crops in controlled environments such as greenhouses [3]. Aeroponic greenhouses are necessary due to the numerous drawbacks of traditional field farming techniques [13]. Regarding water usage, aeroponics recycles 99% of the water utilized. Due to the absence of pesticides or fertilizers, the fruits and vegetables are fresh and do not necessitate washing prior to consumption. The aeroponic method offers greater advantages than the hydroponic system when it comes to spraying the nutrient solution directly to the plant roots [14].

2. CATEGORIES OF SOILLESS FARMING

Soilless farming, a method gaining traction in modern agriculture, involves nurturing plants in a nutrient-rich solution without traditional soil. Utilizing artificial mediums like sand, gravel, rock wool, peat moss, and others, this approach supports root development. Recent advancements, such as the advent of grow bags, net caps, and custom-tailored fertilizer solutions, have garnered attention for their efficacy in enhancing crop growth. These cultivation methods, pioneered for soilless farming, have been studied extensively, notably by Gruda and Tanny [15,16]. Soilless farming can be broadly categorized into two primary systems: open soilless systems and closed soilless systems, each offering distinct benefits and applications.

2.1 Soilless Open Cultivation

This growing system utilizes a dripping framework to deliver the necessary dissolved nutrients to plants, promoting their growth and development. Typically, this approach should include a defined area at one end where excess water can flow off, which is controlled inside the area where the roots of plants are located. This ensures that plants can efficiently absorb the nutrients that are available to them. The fertilizer solutions in this system are single-use and not recirculated or recycled. A key benefit of this method is the reduced risk of plant infection, as the nutrient solution remains stable without constant fluctuations. [17]. It is further categorized into the following kinds, as shown in Table 1.

2.2 Closed Soilless Cultivation

Using this technology, nutrients in solutions are cycled, evaluated, and maintained. Regular nutrient supplement maintenance is crucial to prevent plant mortality due to improper inspection causing loss of equilibrium. The main problem of this technique is its electrical dependence [18].

3. HYDROPONICS: SOIL-FREE GROWING

Water culture and substrate culture are two forms of hydroponics, a method of cultivating plants without soil as a growth medium [19]. The quality of the harvest from soilless cultivation is considerably superior when compared to soil-based farming [7]. There is zero likelihood of encountering any weed infestation, pest or disease attack, or soil-borne insects. In hydroponics, nutrients are carefully supplied to the roots of plants, which enhances plant growth by accelerating their development [20]. A soilless culture, when compared to field soil, may effectively meet the essential requirements for crop growth and achieve comparable levels of growth and yield production [6]. Various types of growing medium are available, such as coco-coir, hydro tons, perlite, vermiculite, peat moss, sawdust, and rock wool. Instead of soil, it utilizes an inert and non-organic substance as a soilless culture, serving as a medium [21]. It possesses several characteristics, including as porosity and a remarkable capacity to retain water. In soilless culture, the irrigation water is carefully controlled, resulting in a 50% reduction in water usage compared to typical soil-based vegetable production [12]. The soilless culture system is a method of growing plants that relies on nutritional solutions and porous growing media. This allows for the creation of a matrix that can maintain the ideal balance of air and water for plant growth [13]. Soilless agriculture is advantageous in urban areas due to its flexibility and capacity to create and maintain adequate conditions [14].

4. HYDROPONICS

Hydroponics is a method of cultivating plants in a nutrient solution, either with or without the addition of an inert media such as gravel, vermiculite, or rock wool, to give support [22]. There are two types of hydroponic systems: the Active system and the Passive system. In a passive system, the plant roots maintain touch with the nutritional solution, while the substrate serves as a means of support for the plants. The Wick system serves as an example of a passive system. In active systems, motor pumps deliver a nutrient solution to plant roots, while a gravity system efficiently drains excess solution for recycling. Examples of active system types include NFT, Deep Water Culture, Ebb and Flow, Drip System, Aeroponic, and Dutch Bucket Method. Researchers suggest that active systems are more efficient than passive systems. [23,24] Hydroponics, a method of plant development without soil, offers more advantages compared to traditional soil-based agriculture. One significant benefit is the absence of pesticides and herbicides, resulting in reduced environmental pollution [11]. Hydroponics has proven to be effective on a large scale in areas with limited access to advanced technology, particularly in rural regions [10]. Hydroponics offers a primary advantage over traditional soil-based farming by significantly reducing water consumption. When comparing plants cultivated in soil vs hydroponics, the plant grown in hydroponics requires 50% less water [9]. Hydroponics, the rapidly expanding sector of agriculture, is projected to become the dominant approach to food production within a few years [25]. The pH and electrical conductivity (E.C.) have a significant influence on the health and vigor of crops in hydroponics. If the pH and electrical conductivity (E.C.) levels are over the optimal range, essential minerals and micronutrients will not be available for uptake by plants [26]. Prolonged exposure of plants to a single solution for over a week leads to significant alterations in the levels of dissolved oxygen, pH, and electrical conductivity (E.C.) of the nutrient solution. These changes have a profound effect on the growth and development of the plants [27]. Through the utilization of nutrients extracted from non-edible agricultural waste, the hydroponic system has shown favorable outcomes in crop production [28]. It is feasible to grow vegetables using an organic nutrient solution in hydroponic systems, as the nutrient solutions used are derived from chemical fertilizers [29]. Liquid organic fertilizer, composed of organic substances suitable for human consumption, can serve as a replacement for chemical nutrients in hydroponic systems that do not use chemicals [30]. A hydroponic system can be utilized for cultivating a diverse range of plants, encompassing vegetables, fruits, flowers, and medicinal crops [31]. This approach is further categorized into the following subcategories [4].

4.1 The Nutrient Film Technique (NFT)

The NFT system, pioneered by Allan Cooper in England during the 1960s, revolutionizes hydroponic farming. It operates by circulating dissolved nutrients through plant roots via shallow water streams in waterproof channels. This unique approach ensures optimal air exposure for root mats, promoting efficient nutrient absorption. Studies attest to NFT systems' superior water and nutrient utilization, outperforming traditional soil-based methods and yielding higher crop yields. Ongoing advancements, including the integration of auxiliary mediums and expanded procedures, continue to enhance NFT technology. Notably, lettuce stands out as a primary crop cultivated using the Nutrient Film Technique.[32]

4.2 The wick System

The wick system is a fundamental type of hydroponic system that often lacks movable components and does not rely on power or water circulation pumps [33]. Therefore, there is no reutilization of nutritional solution; instead, the plants absorb the solution by the capillary action of their roots and fibers [34]. As a result, this method proves particularly advantageous in regions with limited or no access to electricity. The wick acts as a conduit, delivering nutrient solution to the roots of potted plants. Research indicates significant effects of this technique on various parameters of *Brassica chinensis* L., such as plant height, leaf number, leaf area, dry weight, harvest index, and fresh weight [58]. However, it is not advisable for long-term cultivation [18].

Table 1. Open soilless cultivation types and descriptions

Type	Description
The root dipping technique	Containers with growth media are stored in a vessel containing an appropriate amount of nutrient solution. The lower section of the pots, measuring 1-3 cm, is in direct contact with the solution [35]. In this area, the roots are partially submerged in the solution and partially floating in the air. This technique is mostly utilized for cultivating little leafy greens [36]. The study found that vegetables cultivated using root dipping hydroponic systems had high levels of iron and calcium. Additionally, jute mallow plants grown in this system exhibited greater plant height, leaf count, stem girth, yield, fruit weight, and fresh weight of stem and root, compared to traditional soil farming systems [37].
Levitation method	This approach involves use miniature pots with Styrofoam sheets to secure plants and allow them to float on a nutritional solution in shallow containers that are 10 cm deep. The nutrient solution is aerated artificially to fulfil the requirements of the growing plants.
Capillary action technique	This approach involves the utilization of pots of different shapes and sizes, which are equipped with perforations at the base. The pots contain inert material and are used to grow seedlings or seeds. After planting, they are placed in shallow containers filled with nutrient solution. Aeration is a crucial factor that affects the overall effectiveness of this system. It can be achieved by using a mixture of aged coir dust with gravel or sand. The nutritional solution is absorbed into the medium through capillary action.

Table 2. Scientific studies on the use of hydroponic systems as a potential substitute for traditional production methods

S. No	Title of the Paper	Parameters Studied	Country	Author
1	An ensemble classifier model is used to predict and perform comparative analysis on the growth rates of leafy vegetables in a DWC (Deep Water Culture) and NFT (Nutrient Film Technique) smart hydroponic system.	Dynamics of plant growth	India	Srivani *et* al., 2022 [38]
2	The objective is to construct a greenhouse using the root dipping technique and hydroponics structure in order to evaluate the efficacy of jute mallow.	Plant height, yield, number of leaves, and stem girth	Nigeria	Olubanjo *et* al.,2021 [39]
3	Comparisons between soil-based and hydroponic systems reveal that tomatoes grown hydroponically demonstrate improved water use efficiency and higher concentrations of lycopene and β-carotene.	Fruit yield, water usage, transpiration, stem elongation, fresh and dry weights, β-carotene, lycopene, total soluble solids (TSS), and total antioxidant activity (TAA).	Uk	Verdoliva *et* al., 2021 [40]
4	Improving lettuce (*Lactuca sativa* L.) productivity and water efficiency through simplified soilless farming in a semi-arid environment.	Leaf count, WUE, stomatal conductance, and yield	Brazil & Myanmar	Nicola *et* al., 2020 [41]
5	The research examines how the growth and yield of okra respond to root dipping hydroponic systems compared to traditional farming methods.	Plant height, leaf count, stem diameter, and root system characteristics.	Nigeria	Olubanjo *et* al., 2020 [42]
6	The research examines how different recirculation intervals and nutrient solution depths impact the growth, productivity, and water usage of coriander grown in hydroponic channels.	Parameters such as plant height, shoot fresh and dry weight, water consumption, water use efficiency (WUE), and visual quality are being measured.	Brazil	Silva *et* al., 2020 [43]
7	An assessment of hydroponic systems for growing lettuce (*Lactuca sativa* L., var. Longifolia) and a comparison with traditional soil-based agriculture.	length of the crop, growth and photosynthetic characteristics, crop quality metrics, water usage, and economy	India	Majid *et* al., 2021 [44]
8	An assessment of tropical tomato plants in a recirculating hydroponic system to determine their growth, yield, nutrient uptake, and water usage efficiency.	Plant growth, dry matter, WUE, NUE, produce yield, and quality	Ghana	Ayarna *et* al., 2020 [45]
9	Tomato production using vine cutting technology in a hydroponic system.	Formation of shoots, quantity of fruits, fruit	Nigeria	Ossai *et* al., 2020 [46]
10	An assessment of hydroponic cultivation techniques as an adjunct to traditional	Rate of germination, vitality of the plant,	India	Gurung *et* al.,

S. No	Title of the Paper	Parameters Studied	Country	Author
	farming methods.	morphology of the roots,pigment content, and yield		2019 [47]

4.3 Water Culture, also Known as Deep-Water Culture (DWC)

In the hydroponics technique, seedlings are submerged in a solution of nutrient-rich, unpolluted water, allowing plants to obtain the necessary nutrients for their growth and development. Rectangular containers with a depth of 10-20 cm are utilized to hold a nutrient solution. These containers include seedlings that are suspended on panels floating on the surface [48]. it is commonly known as deep flow technique, floating raft technology. Typically, it is employed for cultivating ephemeral, foliate vegetables and aromatic plants. Oxygenation is achieved by employing an air stone linked to an air pump, generating bubbles that oxygenate the surrounding water. Alternatively, sufficient quantities of hydrogen peroxide (H_2O_2) can be used. To maximize growth, it is necessary to maintain the optimal levels of oxygen concentration, conductance, and pH [17]. As plants grow and use resources, the pH and electrical conductivity (EC) of the water may vary. Therefore, regular monitoring is essential as excessively high or low pH levels can impede nutrient uptake by plants. Commonly cultivated within this framework are lettuce, Chinese cabbage, spinach, and a variety of other crops.

4.4 Ebb and Flow Systems

This method shares similarities with the trickle system, utilizing the same array of containers. Ebb and Flow represent two distinct phases of the tide cycle: Ebb denotes the period of water recession and drainage, while Flow corresponds to the subsequent period of water resurgence and elevation. The containers are filled with an inert substance, acting as temporary reservoirs for water and mineral nutrients in liquid form. An intermittent flooding system is implemented using a pump, submerging the roots in a nutrient solution for a brief period (5 to 10 minutes), followed by deactivation to allow solution evacuation. This process facilitates nutrient supply to plants, with the solution being recirculated thereafter. The frequency of flooding depends on the water retention capacity of the medium, with highly retentive media requiring daily flooding and others requiring 2 to 6 flooding sessions per day, each lasting a few minutes. Consequently, the efficacy of this system and plant development hinge upon the quality of the medium, making it suitable for a variety of vegetables and crops with extensive root systems [49].

4.5 Drip Irrigation Hydroponic System

The drip irrigation hydroponic system involves setting up a dual-container system, with one container positioned atop the other. The upper container is designated for vegetable cultivation, while the lower container serves as a reservoir for a nutritional solution. Utilizing miniature emitters, the system administers the solution directly to the plants, resembling a trickle or micro-irrigation system. Water is drawn from the reservoir through a main line and distributed via lateral lines parallel to the plants. Oxygenation of water is achieved using an aquarium stone [50]. There are two main categories of drip systems: recirculating (recovery) systems and non-recirculating (non-recovery) systems. In recirculating systems, surplus water is returned to the tank for reuse, while in non-recirculating systems, excess water is discarded. Despite some wastage, drip systems are highly attractive to commercial growers due to their efficiency and minimal reservoir management requirements. In conclusion, a drip system is a versatile and pragmatic method of hydroponics. This system is suitable for a diverse array of plants and herbs and offers enhanced control over the distribution of water and fertilizer. Given the significance of hydroponic systems in contemporary agriculture, various research has been carried out to assess its potential and advantageous effects in providing sustenance for the future world population (Table 2). Therefore, it is crucial for researchers to propose advanced technological advancements, and for farmers to embrace them, in order to increase productivity and reduce the impact of both natural and human activities on the environment. This will help maintain ecological balance and contribute to the overall objective of sustainability.

6. AEROPONICS

Aeroponics is the method used in contemporary agriculture to cultivate plants without the use of soil [1]. In an aeroponic system, the roots of the plants are moistened with a nutrient solution by the atomization of the nozzle. A nutrition solution is sprayed at intervals of two to three minutes. Crops can be cultivated in a soilless medium within an aeroponic system, utilizing artificial light instead of natural light. The aeroponic system consists of a growing chamber, net pots, an irrigation system, a motor, a digital timer, and a nutrient tank. This technique enables the growing of fresh and nutritious fruits and vegetables both indoors and on rooftops [14]. If a plant in an aeroponic system is being targeted by pests or diseases, it can be easily relocated. Continuous monitoring of pH and nutrient concentration ratios is essential in an aeroponics system. The aeroponics system requires additional oversight and meticulousness in order to establish a partially or fully enclosed environment [51]. The plants grown in the aeroponics growth chamber are specifically designed to get optimal aeration, resulting in accelerated plant development. This technique enhances the oxygen supply to the roots, hence creating a conducive environment for plant growth [52]. Growers in industrialized nations may benefit from improved access to high-quality seed through the use of aeroponics systems, which can enhance revenue and reduce production costs [53]. Within this setup, the plant has the potential to grow to a height ranging from 15 to 30 cm. The aeroponic system possesses the capacity to cultivate plants during periods of time when they are not typically grown. An aeroponic system can be used to raise several herbs by utilizing a single fertilizer solution [54]. Aeroponics is very suitable for studying water stress and root morphology due to its ability to precisely adjust the moisture content in the root zone and the amount of water provided [13]. Aeroponics has proven to be commercially successful in propagating plants, germinating seeds, producing seed potatoes, growing tomatoes, cultivating leaf crops, and cultivating microgreens [55].

6.1 Configuration of Aeroponic System

An aeroponic system involves suspending plant roots within an enclosed environment located in a growing chamber. To ensure optimal humidity and darkness in the chamber, a black poly sheet is used to line the growing chamber. In aeroponics, a nutrient solution is sprayed onto plant roots using nozzles that are installed in evenly spaced PVC pipes. The motor responsible for pumping the nutrient-rich solution at a high pressure is attached to the pipeline. A digital timer is linked to the pump in order to regulate the timing of the fertilizer spraying within a designated timeframe. The size of the aeroponics unit system, the plant being grown, the distance between the nozzle and its pressure, the spacing of net pots on the growth chambers, the pump capacity of the motor, the nutrient spraying, and the interval between consecutive sprayings may vary. The growth chamber's pipe is linked to a nutrient tank that reuses the nutrient solution that drops from the suspended roots in the growth chamber [56]. The growth chamber and misting system have the ability to fully manage the root zone environment, which includes factors like as temperature, nutrition content, pH, humidity, misting frequency and duration, and oxygen availability [5]. Supplementary sensors can be employed to track the duration and frequency of a nozzle being in the "ON" and "OFF" states, with the purpose of controlling the quantity of nutrients being dispensed [31]. An aeroponic system offers more flexibility in terms of its design and size compared to a hydroponic system. Regardless of their orientation, both vertical and horizontal systems commonly employ the same mist delivery technology [57]. If there is a substantial distance between misting sprayers and the roots, the roots will experience a decrease in the availability and absorption of nutrients [58].

6.2 Functioning of the Aeroponic System

In an aeroponics system, the roots are regularly exposed to a nutrient solution that is either sprayed continuously or at regular intervals [12]. The nutrient solution is transported by a motor through pipes that are connected to the irrigation system located within the growth chamber [59]. The size of the nutrient tank is determined by the type of crop and the required amount of water. The aeroponics system utilizes a substrate to cultivate plants within net pots. Within the cultivation chamber, the plant roots are suspended [60]. The nutritional solution is atomized and sprayed into the roots of the plants, after which it drains back into the nutrient reservoir for potential reuse [4]. To ensure optimal plant growth, the temperature and humidity levels in the growing chamber can be modified [61]. In order to inhibit the proliferation of the algae, a black sheet is positioned over the growth chamber to obstruct sunlight [62]. The presence of a pollution-free atmosphere and an ample supply of oxygen promotes rapid growth of plant roots in the growth chamber, resulting in increased plant yield in the aeroponics system [63].

6.3 Optimal Droplet Size for an Aeroponics System

An optimal droplet size for most plant species falls between the range of 20 to 100 microns. In this specific region, the minuscule droplets fill the air, ensuring that the humidity levels in the growth chamber are maintained. The roots primarily interact with droplets ranging between 50 and 100 microns in diameter. Spray droplets smaller than 30 microns typically remain suspended in the air as a fog, while those larger than 100 microns often descend to the ground before reaching the roots. When water droplets are excessively large, the availability of oxygen to the root system is reduced [3].

Table 3. Presents scientific papers investigating the use of aeroponic systems as a sustainable alternative to traditional agricultural methods.

S. No	Title of the Paper	Parameters Studied	Country	Author
1	An aeroponic evaluation was conducted to assess the diversity in root morphology, nitrogen usage efficiency characteristics, and yield attributes of different potato cultivars in India.	The characteristics being studied include the structure of the root system, the height of the plant, the area of the leaves, the weight of the roots and shoots, the peculiarities of the tubers, and the factors related to nitrogen use efficiency (NUE).	India	Tiwari *et* al., 2022 [64]
2	The study investigates the impact of plant growth promoting rhizobacteria (PGPRs) and chemical fertilizers on the growth of various potato cultivars in aeroponic culture settings.	The parameters to be measured are the quantity and mass of the smallest tuber, the number of stolons, the duration till tuberization, the height of the plant, and the length of the stolon.	Iran	Nasiri *et* al., 2022 [65]
3	Exploration, analysis, and possible application of *Cannabis Sativa* L. root systems grown via aeroponic cultivation.	The topic of interest is the growth of plants and the presence of certain bioactive compounds in their roots, including β-sitosterol, stigmasterol, campesterol, friedelin, and epi-friedelanol.	Italy	Ferrini *et* al., 2021 [66]
4	The research examines the interplay among planting density, harvest timing, and the growth, yield, and dormancy of potato minitubers cultivated through aeroponics.	The research delves into how harvesting dates and planting densities influence the growth and yield of potatoes, encompassing factors such as stem and leaf count, as well as the quantity and fresh weight of small tubers.	Brazil	Balena *et* al., 2021 [67]
5	Comparative assessment of potato cultivation across multiple soilless systems.	Plant height, root length, leaf count, stem diameter, leaf area, leaf length, and potato yield.	Egypt	Khater, 2021 [68]

Table 4. Presents scientific studies investigating various growth media employed in soilless farming.

S. no	Title of the Paper	Parameters Studied	Country	Author
1	The impact of using hemp fiber and rock wool as growing media on yield, secondary metabolites, substrate properties, and greenhouse gas emissions in soilless tomato cultivation.	Leaf area, plant height, crop output, and fruit quality.	Germany	Nerlich *et* al., 2022 [69]
2	The research examines how the growing substrate, method of nutrient delivery, and size of saffron corms affect flowering, growth, photosynthetic efficiency, and cormlet production in hydroponic cultivation.	Flowering characteristics, growth parameters, photosynthetic rate, stomatal conductance, and crop yield	Egypt	Dewir *et* al., 2022 [70]
3	Utilizing sawdust and bark-based substrates for soilless cultivation of strawberries: approaches to irrigation strategies and management of electrical conductivity.	Potential for enhanced efficiency and productivity.	Canada	Depardieu *et* al., 2016 [71]
4	The influence of different growth conditions on the physical morphology of Rockmelon (*Cucumis Melo Linn* cv. Glamour) seedlings.	The parameters being measured are the height of the plant, the number of leaves, the total area of the leaves, and the circumference of the stem.	Malaysia	Rauf *et* al., 2022 [72]
5	The aim of this study is to create and improve substrates for soilless tomato growing using recycled raw materials such as coconut fiber and bagasse. These substrates will be enhanced with soil microorganisms including Arbiscular Mycorrhizal Fungi, *Trichoderma spp*., and *Pseudomonas spp*.	Topics covered include tomato cultivation, plant health and growth, and both biological and environmental factors that can impact tomato plants.	France	Masquelier *et* al., 2022 [73]

The aeroponic system's capacity to precisely regulate the size of the nutrient solution droplets can improve the conditions that promote successful development of plant roots [74].

7. TYPES OF GROWING MEDIUM

A solid media culture refers to a medium, other than soil, that is inert and consists of either organic or inorganic material. This medium provides support for plant growth and can take several forms. The media utilized must possess a high-water retention capacity, porosity, and other essential features that facilitate the adequate supply of nutrients to the plants through the nutrition solution. Additionally, it should ensure good oxygenation of the roots to maintain the plants' health. To guarantee optimal growth of seedlings, it is imperative to maintain a high standard of media quality. Various media are utilized to nurture plants due to their superior physical qualities and ability to provide necessary nutrients for sustained plant growth and efficient resource utilization. Multiple mediums, including coco coir, hydroton, perlite, vermiculite, peat moss, sawdust, rock wool, coarse sand, etc., are utilized to support plant growth [75]. These mediums are highly adaptable for soilless production because to their exceptional capacity to retain moisture and nutrients, promote optimum aeration, and provide efficient exchange of oxygen. Furthermore, vermiculite possesses a substantial quantity of potassium and magnesium, and it also exhibits resistance to decay, so aiding in the enhancement of soil composition. In addition, certain mediums are resistant to microbial degradation, although they are more expensive than other materials and cannot be substituted with other insulation materials. Various ways utilized to utilize these expanding mediums for crop cultivation include the hanging bag technique, grow bag technique, trough or trench technique, and pot technique. Multiple studies have provided confirmation of the significant impact that growth medium have on plant growth, nutrition, and ultimately agricultural productivity. Table 4 includes several research that discuss the utilization of growth media.

8. HYDROPONIC NUTRIENT SOLUTION FOR SOILLESS CULTIVATION

The aqueous solution encompasses essential nutrients crucial for plant growth and development, alongside oxygen and water. The current roster of critical growth nutrients comprises 17 elements: carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, copper, zinc, manganese, molybdenum, boron, chlorine, and nickel [76]. Carbon and oxygen are sourced from the atmosphere [77].

Table 5. Concentration ranges of key mineral elements and commercial nutritional solutions [15,78]

Nutrient	Cooper (1979)
N	200-236 mg L^{-1}
P	60 mg L^{-1}
K	300 mg L^{-1}
Ca	170-185 mg L^{-1}
Mg	50 mg L^{-1}
S	68 mg L^{-1}
Fe	12 mg L^{-1}
Cu	0.1 mg L^{-1}
Zn	0.1 mg L^{-1}
Mn	2.0 mg L^{-1}
B	0.3 mg L^{-1}
Mo	0.2 mg L^{-1}

The nutrient solution is formulated by dissolving inorganic salts in water, leading to the release of ions that are subsequently absorbed by the plant's root system. Regular monitoring of nutrient levels in the solution is advised, ideally conducted between 6:00 and 8:00 am. Daily water and nutrient requirements vary depending on the crop variety and plant age. Apply the nutrient solution directly to the plant's roots, avoiding foliage contact to prevent leaf scorching. Regular drainage and replacement of approximately 20-50% of the nutrient solution in the hydroponic system are necessary to prevent harmful ion accumulation. Table 5 outlines the nutrient levels utilized in soilless agriculture, while Table 6 provides optimal electrical conductivity (EC) and pH levels for various crops.

Table 6. Ideal pH and EC range for vegetables cultivated hydroponically (Sharma *et* al., 2018). [15,79]

Crops	EC (dsm^{-1})	pH
Asparagus	1.4-1.8	6.0-6.8
Broccoli	2.8-3.5	6.0-6.8
Cabbage	2.5-3.0	6.5-7.0
Egg Plant	2.5-3.5	6.0
Lettuce	1.2-1.8	6.0-7.0
Spinach	1.8-2.3	6.0-7.0
Tomato	2.0-4.0	6.0-6.5

9. PROS AND CONS

Soilless farming is a renowned and advantageous strategy in modern times, offering several benefits compared to traditional agriculture systems. It provides an advantageous climate for plants and enables year-round production with little water and nutrient requirements compared to traditional agriculture. Multiple studies have demonstrated that soilless farming has the capacity to provide greater yields compared to traditional soil-based cultivation. The regulated system of hydroponic farming also mitigates both living organism-related and non-living environmental factors that can negatively impact crop development, hence supporting sustained agricultural productivity. Soilless farming provides substantial advantages in resource preservation and ecological sustainability. Although it possesses some advantages, it also presents certain disadvantages such as the need for technical expertise to operate the system, a greater initial investment, the need to monitor various plant growth factors (such as pH, EC, and nutrient content), and the demand for electricity. Hence, it is imperative to thoroughly deliberate before commencing soilless.[80]

10. POTENTIAL PROSPECTS OF HYDROPONICS IN INDIA

Hydroponic gardening in India lacks widespread public acceptance, much like the popularity of hydroponics on the moon. A significant number of individuals in India possess farms that are situated close to the poverty threshold. Consequently, their limited access to education, lack of investment, and reluctance to step out of their comfort zones are contributing to a negative and unfriendly stance towards hydroponics. Furthermore, hydroponics is not widely employed by rural farmers in India. Despite these limitations, hydroponic farming in India has promising possibilities for various reasons:

I. Initially, India's megacities are struggling with a shortage of water, and agriculture is a significant consumer of water. By shifting from conventional agriculture to water-efficient technology such as hydroponics, it is feasible to achieve water savings of over 80%. The conserved water can then be diverted to the potable water system, thereby resolving an urgent problem.
II. Additionally, a substantial proportion of the veggies consumed in India contains lingering chemicals that have the potential to be detrimental to one's health. India's methods for tracking and monitoring pesticide residue in food are not well-established, unlike those in wealthy countries. With the increasing recognition of health hazards, customers in India are actively searching for healthier items and are willing to pay a higher price for them. Hydroponically cultivated crops possess the capacity to offer food commodities that are free from chemicals, Therefore, fulfilling the requirement for items that are more secure.

Considering the expanding demand for organic products and the rising curiosity among farmers and researchers regarding its viability as a sustainable farming method, it is probable that India would gradually increase the cultivation of hydroponic crops. Additionally, it will be essential to consider the requirement of offering monetary and technical support to farmers, as well as the limitations on crop selection when utilizing hydroponic technology [81].

11. CONCLUSION

Anticipated future industrialization is set to experience a significant surge as the quality of soil for farming becomes increasingly difficult. Given the continuous expansion of metropolitan regions, it is advisable to implement soilless cultivation as a means to enhance both the productivity and quantity of plants. Both hydroponics and aeroponics have the ability to generate substantial quantities of top-notch crops on a huge scale. Furthermore, it can greatly enhance the per capita availability and utilization of fruits and vegetables. Hydroponics and aeroponics systems are more efficient than traditional agricultural methods in terms of water utilization. They significantly reduce water losses and improve water usage efficiency. By embracing cutting-edge technologies and innovative methodologies, vegetable growing can be elevated to the realm of next-generation science.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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