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Soilless farming: An innovative sustainable approach in agriculture

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Abstract
The exploding population has aided to the exhaustion of land and water resources which eventually has impacted their availability and also causes degradation of such crucial natural resources, which poses a major threat to the ecological balance and sustainability. In addition, the world population is expected to touch the mark of 9.8 billion by 2050 with simultaneous alarming reduction, deterioration of farming land and loss of fertile soils owing to industrialization, urbanization and climate change scenario, which is a major concern regarding global food security. Moreover, conventional agriculture is facing major challenges of biotic and abiotic stresses that hamper the crop production and hence cause economic loss. Therefore, it becomes necessary to develop novel technologies coupled with advanced production techniques to overcome the present scenario and to secure the future. This review focuses on the soilless farming which could be adopted to address the aforementioned challenges. The different techniques used in soilless farming are hydroponics, aeroponics, aquaponics and various solid media cultures, provided with nutrient rich solution. Soil less farming has high yielding, high nutritional values and economically feasible which could serve as a measure to overcome the threat of global food security, malnutrition concern and also in economically uplifting of the farming community.

Keywords: Aeroponics, aquaponics, climate change, food security, hydroponics, soilless farming

Introduction
Soil is by far the primary medium supporting crop growth because of its moisture and nutrition capacity, along with its ability to perform as a buffer in the instance of an abrupt shift in soil pH (Ellis *et al*., 1974) [34]. It provides support, essential nutrients, water, aeration etc. necessary for plant growth. However, soil has some limitations of biotic (disease, pests) and abiotic (drought, salinity, nutrient deficiency, soil pollution, poor water quality etc.) stresses which hamper the crop production. In addition, soil fertility and productivity has been significantly declined coupled with reduction in the available land per person (Lal, 2015; Lehman *et al.*, 2015) [68, 70]. One of the major challenges today is to develop a sustainable food system and eradicate poverty and hunger. However, the provision of food to future generation in a sustainable manner is a substantial concern, especially for increasing population (Alexandratrs and Bruinsma, 2012) [3]. According to reports, the future population is anticipated to touch the mark of 9.8 billion by 2050 with major share of developing nations (Cohen, 2002; UN, 2011) [25, 120]. Therefore, an incremental food production of about 60-70% will be required to feed this population in a proper manner, globally (Foote, 2015) [41], however, there is no land availability for cultivation (FAO, 2020) [36], hence, rising issues must be addressed. The dramatic growth in population has led to ecological deterioration, resource depletion, uneven distribution of food, and numerous occurrences of undernourishment. An outcome of a survey has revealed that there were 820 million undernourished people in various regions of the world, which could worsen in future if the current circumstances continue to prevail. On the other side, the farming land is shrinking at an alarming rate due to industrialization and urbanization and the fertile soil are also at stake because of degradation and climate change scenario. In India, according to an agricultural census 2015-16, the average farm size was 2 ha in 1976-77 which has reduced to 1.08 in 2015-16, clearly indicating that the farm land will be less than a hectare in coming years. Furthermore, the arable land in Jammu and Kashmir has shrunk from 0.14 ha per person in 1981 to 0.06 ha per person in 2012. Kashmir had a net of 4, 67,700 ha of agricultural land in 2015, which has dropped to 3, 89, 000 ha in 2019, with pulse production declining from 14,600 ha to 12,767 ha from 2015-2019, and area under maize

cultivation decreased by 20% between 2003-2012 owing to land use changes. The Kashmir valley lost approximately 22, 000 ha of paddy land from 1996-2012. On an annual estimate, Kashmir loses an average of 1375 ha of agricultural land (Jammu and Kashmir Economic Survey Report, 2017-18) [58]. The number of mega cities is increasing rapidly and migration from rural to urban areas is also increasing, with current residence of 56% of world population in cities (Shackleton *et al*., 2009) [104]. The soil is not usually available in metropolitan areas, or there is a paucity of healthy land attributed to unsuitable geographic or topographic aspects, along with intensive road and building construction, and if there is, then it may hold contaminants that are not beneficial to plants. Climate change is another factor contributing to the increased ecological, economical, and social issues across the globe (Eileen, 2009) [33]. The increased temperature, irregular distribution of rainfall (Bisbis and Gruda, 2018; Gruda *et al.,* 2019) [17, 48], suggesting that these climatic changes can negatively influence natural resource availability (fertile land and water) and poses threats to human health and sustainability (Bisbis and Gruda, 2018; IPCC, 2007) [17, 56]. Several undeveloped nations in tropical areas are susceptible to climate change owing to their heavy reliance on rain-fed farming, economic stagnation, and restricted access to technological innovations and advanced agricultural approaches (Dowuona *et al.,* 2014) [32]. Under such circumstances, researchers must develop novel technologies and provide the solution and therefore, such technologies must be adopted in order to withstand the aforementioned challenges. One of the emerging and promising techniques among the latest technologies to overcome the current threats is soilless farming. It is a revolutionary innovation in the field of agriculture and the appropriate strategy for a continual delivery of high quantity and quality produce (Sardare and Admane, 2016) [100]. Soilless farming is a technique of crop production without soil or within solid media culture or water culture, where nutrients are provided artificially to the plants for their growth and development. The different types of stresses (biotic and abiotic) could also be managed in soilless farming since it is a controlled system. This approach has various socio-economic advantages, along with the capacity to deal with rising global food challenges, malnutrition, efficient utilization and management of natural resources, hence conserve ecological sustainability with continuous year round provision of enough and hygienic food supply. It is a truly excellent crop growing approach for all nations with limited farmland, constant changing climate, and escalating food challenges with indigenous population (Sardare and Admane, 2013) [101]. Several soilless methods had been adopted to cultivate the plants in a controlled environment. Although, soilless farming technology mainly focuses on hydroponics, aeroponics, aquaponics and solid media cultures (Texier, 2013) [115] and in this regard they will be discussed separately in the following sections in detail. There are various crops grown in soilless cultures including cereals, vegetables, fruits, condiments, flowers, medicinal crops and fodder crops (Sharma *et al.,* 2018) [105]. The crops cultivated in soilless medium has enhanced yielding and nutritional values (Balashova *et al.,* 2019; Sankhalkar *et al.,* 2019; Singh *et al.,* 2019; Nicola *et al.,* 2020; Majid *et al.,* 2021) [11, 99, 109, 84, 75] which could serve as a measure to overcome the threat of global food security and malnutrition concern. The developed nations are working to improve the efficiency and increase the production; however, this is still in infancy in developing nations to be adopted by the farmers since it requires technical knowhow to operate the system.

Historical evolution of soilless farming

Soilless farming has a prolonged history dating back to ancient civilizations; however, adequate information has not been documented for various reasons. There are numerous prime examples, including Aztecs and Egyptian hieroglyphics, as well as the hanging garden of Babylon, which reveals that soilless farming was followed in many past civilizations. Sir Francis Bacon pioneered the practice of growing plants without soil in his book Sylva Sylvarum in 1627. John Woodward proposed a more comprehensive publication concerning water culture in 1699. He was a fellow of the Royal Society of England, and concluded that the plants/vegetables cultivated in less pure water grew better than those planted in distilled water, which he ascribed to certain minerals in water derived from soil. As a result, this soil-water mixture became the first man-made hydroponic nutrient solution (Waiba *et al.,* 2019) [124]. His research was afterwards followed by the majority of European plant physiologists in order to build various grounds. They proved that plant roots absorb water and nutrients, transferring through the stem and water escapes into the atmosphere via leaves and draws carbon dioxide from the air. However, until the contemporary theories of chemistry made substantial advances in 17th and 18th centuries, precise knowledge of what exactly plants take up was ambiguous. Therefore, following the advancement, remarkable breakthroughs were accomplished in laboratory studies of plant physiology and nutrition between 1800s and 1920s. Later during 1937, Professor William Frederick Gericke coined the term "hydroponics" to describe crop cultivation with roots immersed in nutrient rich solution. In 1940, he authored "Complete Guide to Soilless Gardening" and despite its limitation of being concerned with water only, his wok is considered the foundation for all forms of hydroponic growing. Furthermore, the nutrient solution known as Hoagland solution, which is being used in the current era, was developed by two plant nutritionists named Dennis R. Hoagland and Daniel I. Arnon at the University of California. Since science progressed, more novel and sophisticated approaches were developed, and one among the additions to soilless farming was the use of growth medium with alternately flooding and draining of an optimal amount of both nutrients and air, which was pioneered by Robert B. and Alice P. Withrow. The practice of cultivation without soil (hydroponically grown vegetables) was also used to feed the passengers on a ship sailing in Pacific Ocean during 1930. Furthermore, in 1945, the United States Air force established one of the largest hydroponic farms on the Island of Hawaii. In India, W. J. Shalto Duglas, an English scientist, introduced the hydroponic technique followed by an establishment of a laboratory in West Bengal and authoring a book named "Hydroponics-The Bengal System". As soilless cultivation gained popularity due to increased scientific acceptance coupled with technological advancement, commercial farms were established in numerous countries between 1960-70, including Abu Dhabi, Arizona, Belgium, California, Denmark, German, Holland, Iran, Italy, Japan, Russian Federation and others (Sardare and Admane, 2013) [101]. This includes the establishment of various computerized and self-automated hydroponics farms around the globe, as well as the widespread availability of hydroponic kits. NASA has conducted substantial hydroponic research in Arizona, Euro fresh Farms in Willcox for their Controlled Ecological Life Support System to grow plants for space (Gruda, 2009; Savvas and Passam, 2002) [47, 103]. Arizona farm produced more than 200 million pounds of tomatoes hydroponically (Javaid, 2020) [59] with complete absence of pesticide residues. In Canada, hundreds of acres of land are dedicated to commercial hydroponic greenhouses that produce tomatoes, peppers cucumbers and a variety of other vegetables (Waiba *et al.,* 2019) [124]. Presently, many commercial firms have created AI-supported software to monitor and control the hydroponic system through mobile phones via the internet or Bluetooth facility (Lakshmanan *et al.,* 2020) [67].

Types of Soilless Farming

Soilless farming is an approach of cultivating plants in nutrient-rich solution using an artificial medium such as sand, gravel, rock wool, peat moss, sawdust, coconut fiber, vermiculite, perlite and so on to provide physical support for root growth. Several innovations have emerged and attracted attention in recent years including grow bags, net caps, and a range of customized nutrient solutions for particular plants. These cultivation methods were designed to be used in soilless farming (Gruda and Tanny, 2014) [49]. Soilless farming is mainly classified into two types *viz*; open soilless system and closed soilless system. In brief, both categories are outlined below:

Open soilless cultivation

In this cultivation system, dripping framework is used to supply the dissolved nutrients to plants required for their growth and development. In general, this method should have a run-off designated at one end, regulated in the root zone to ensure optimum uptake of available nutrients by plants. The nutrient solutions in this system are only used once and are not re-circulated or recycled. Therefore, one of the primary benefits of this system is that there won't be any risk of infection in the plant system owing to regular changes in the nutrient solution (Jones, 2005) [60]. It is further divided into following types (Table 1):

Table 1: Types of open soilless cultivation and their description

Type	Description
Root dipping technique	Pots containing growth media are kept in a container having suitable quantity of nutrient solution. The lower portion of the pots (1-3 cm) remains in direct contact with the solution (Hayden, 2004) [54] where roots are half submerged in the solution and partly suspended in the air. This method is mostly adopted for growing small leafy greens (Rousos and Harrison, 1986) [97]. It was observed that vegetables grown in root dipping hydroponic systems contains excellent iron and calcium levels, and jute mallow had higher plant height, the number of leaves, stem girth, higher yields, higher fruit weight, fresh weight of stem and fresh weight of root compared to soil farming systems (Olubanjo *et al.,* 2021) [85].
Floating technique	In this technique, small pots with Styrofoam sheets are used to fix plants and enable them to float on nutrient solution in shallow containers of 10 cm depth. The nutrient solution used, is artificially aerated in order to meet the needs of the growing plants.
Capillary action technique	In this technique, various forms and sizes of pots are used having holes at the bottom. These pots are filled with inert media, and seedlings or seeds are planted before being placed in shallow containers having nutrient solution. Aeration is one of the significant parameters that influence the overall successful functioning of this system, which could be maintained by utilizing old coir dust mixed with gravel or sand. The nutrient solution enters the medium by capillary action.

Closed soilless cultivation

In this technique, as the name implies, the nutrients in solutions are circulated, examined and maintained. Frequent maintenance of nutrient supplements is required, since inappropriate inspection can result in loss of equilibrium, which can lead to plant death. The primary drawback of this approach is that it is reliant on electricity (Lee and Lee, 2015) [69]. It includes following types, which are discussed further in the following subsections:

Hydroponics system

The word Hydroponic is originated from the Greek terms *hydro* indicating “water” and *ponos* denotes “labor/working”, which was introduced by W. F. Gericke in 1930s. It is one of the soilless farming techniques where plants are cultivated using mineral nutrient solutions. These nutrient solutions contain precise quantities of fertilizers required for a specific plant (Mok *et al*., 2014) [80] and inert materials supplied with nutrient solution are also used for root growth (El-Kazzaz and El-Kazzaz, 2017; Sardare and Admane, 2016) [35, 100]. Hydroponics has been used effectively to raise a wide range of crops including lettuce, cucumber, tomato, herbs and many kinds of flowers (Asao, 2012) [7]. It has several benefits over traditional cultivating system, including rapid growth, high productivity, ease of handling, efficient water use (Barbosa *et al.*, 2015) [14] and reduced fertilizer use (Rana *et al.*, 2011; Cuba *et al.*, 2015) [94, 27]. In addition, roots do not have to search for mineral elements, and crops can grow closer together, leading to increased output from less space (Jones *et al.,* 1991) [61]. As a result, it is increasingly being adopted by commercial industries to enhance the production. The nutrient concentration of solution is managed and monitored to detect the symptoms and nutrient deficiencies or toxicity in the plant system (Adrover *et al.*, 2013 and Cuba *et al.*, 2015) [2, 27]. Additionally, this approach has a tendency to eradicate the soil-borne biotic and abiotic stresses (Harris, 1992) [53]. Therefore, it becomes financially viable and lucrative, while simultaneously laborious for large areas (Pullano, 2013) [90]. Hydroponics has proven to be extremely beneficial in toxicological investigations on the buildup of numerous toxins in plants, in the execution of scientific research on native and exotic crops for economical or therapeutic uses, and also in conventional crops such as vegetables and ornamentals. Therefore, the combination of all the benefits makes hydroponics system more productive than soil based cultivation system. The global hydroponic market was of a value of 9.5 billion USD in 2020 and is anticipated to account for USD 17.9 billion by 2026, increasing at cumulative annual growth rate (CAGR) of 11.3% during the forecasting period (Global Forecast, 2026) [43]. This rise in hydroponic sector can be ascribed to increased acceptability of controlled environment agriculture. In India, the hydroponic market is predicted to grow at a CAGR of 13.53% during the forecast period (2021-27), clearly depicting that the adoption of hydroponics in India is increasing, where fruits, vegetables and flowers accounts for the majority of the market (DataM Intelligence Analysis, 2022) [28]. This technique is further classified as follows (Ali, 2017) [4].

Nutrient film technique (NFT)

NFT is a closed hydroponic system designed by Allan cooper in England in the 1960s. In this method, dissolved nutrients in a solution are circulated through the bare roots of plants as shallow stream of water in a watertight gully, known as channels. The depth of the circulating flow is quite shallow not more than a thin film of water, ensuring the root mat developed at the bottom of channel receives an appropriate air exposure. A thin layer develops on the roots, from where the plants acquire required oxygen and nutrients (Morgan, 2009) [81]. As a result, NFT becomes water and nutrient efficient, and there are numerous studies evaluating the potential benefits of this approach. Upon comparison to the protected soil-based growth system, NFT has proved to be an effective hydroponic approach that provided nutritionally improved and greater harvests (Majid *et al.*, 2021) [75]. Recently, this system has been modified with various supporting medium and growing techniques, with lettuce being the most common cultivated crop using NFT.

Wick system

Wick system is the basic form of hydroponic system; traditionally contains no mobile parts and does not require electricity nor uses water circulation pump (Shrestha and Dunn, 2013) [107]. Hence, there is no recirculation of nutrient solution instead the plants absorbs solution via capillary action of the roots and fibres (Ferrarezi and Testezlaf, 2016) [40]. As a result, it can be quite useful in areas with negligible or no assess to electricity. The wick is a component, connecting the potted plants and nutrition, aiding in the circulation of nutrient solution to the root zone. An outcome of a study has revealed a significant effect of this system on plant height, leaf number, leaf area, dry weight, harvest index and fresh weight in Brassica chinensis L. (Harahap *et al.*, 2020) [52]. However, it is not suggested for long-term cultivation (Lee and Lee, 2015) [69].

Water culture or deep-water culture (DWC)

In this technique of hydroponics, seedlings are immersed in nutrient rich, fresh water, and plants acquire the required nutrition for their growth and development. Rectangular containers of 10-20 cm depth filled with nutrient solution are used, containing seedlings hovering in panels on the surface (Van *et al.*, 2002) [121]. Hence, it is often referred as deep flow technique, floating raft technology or raceway. It is generally used to grow short-term, leafy greens and herbs. The oxygenation is achieved through the use of an air stone connected to an air pump, which generates bubbles and oxygenates the surrounding water, and (or) by using appropriate amounts of hydrogen peroxide (H_2O_2). In order to optimize growth, the concentration of oxygen, conductance, and pH must be maintained (Jones, 2005) [60], as plants grow & utilize resources, the pH and EC of the water fluctuates. Therefore, regular surveillance is required since nutrient availability to plants would be impeded if the pH is too high or low. Lettuce, Chinese cabbage, spinach, and other vegetables are commonly cultivated in this framework.

Ebb and Flow systems

This method is comparable to the trickle system utilizing an identical set of containers. Ebb and Flow are two tide phases, with Ebb being the exiting period when water drains and Flow being the entering period when water rises again. The pots contain an inert material that acts as a transitory reservoir of water and aqueous mineral nutrients. A pump is used to flood the system periodically with nutrient solution for a brief period of time (5 to 10 minutes), submerging the roots before turning off the pump to allow the system to drain. This result in the provision of the nutrients to plants and the solution is re-circulated. The rate of flooding the system depends on the medium's water retentive capacity. The highly retention media require only one flooding a day, whereas others necessitate 2 to 6 flooding per day, with every "flood" round lasting merely few minutes. Therefore, the quality of medium determines the plant growth and success of this system. All sorts of vegetables can be grown and is also appropriate for crops with enormous root balls (Halveland, 2020) [51].

Drip hydroponic system

In this approach, the system is built using two containers, one at the top and another at the bottom, with vegetables grown in the top container and nutrient solution kept in the bottom container. As the name implies, it uses small emitters to deliver the solution directly to the plants. The water is pumped from the reservoir via main line, and further divided into lateral lines that run directly alongside plants. Hence, it is also called trickle or micro irrigation system. Oxygenation of water is achieved by using an aquarium stone (El-Kazzaz and El-Kazzaz, 2017) [35]. There are two types of drip system such as recirculating or recovery system and non-recovery or non-circulating system. When water is delivered to the artificial medium, the roots do not absorb all of it. Therefore, the excess water in recovery method is permitted to drain back into the tank, but excess water in the non-recovery system is permitted to run off as waste. Although drip systems are relatively conservative, the magnitude of wastage is generally small, making it very appealing to commercial growers since it requires minimal reservoir management. Conclusively, a drip system is a diverse and practical approach of hydroponics. It is appropriate for wide range of plants and herbs and provides greater regulation of water and fertilizer delivery. Different types of hydroponic systems are graphically presented in figure 1.

Considering the importance of hydroponic systems in modern agriculture, numerous studies have been conducted to evaluate its potential and beneficial impacts to feed the future population globally (Table 2). Hence, it becomes essential for researchers to put forward high-tech innovations and farmers to adopt in order to enhance the output and minimize the influence of various natural and anthropogenic activities to preserve the ecological balance, which would eventually serve and uplift the universal goal of sustainability.

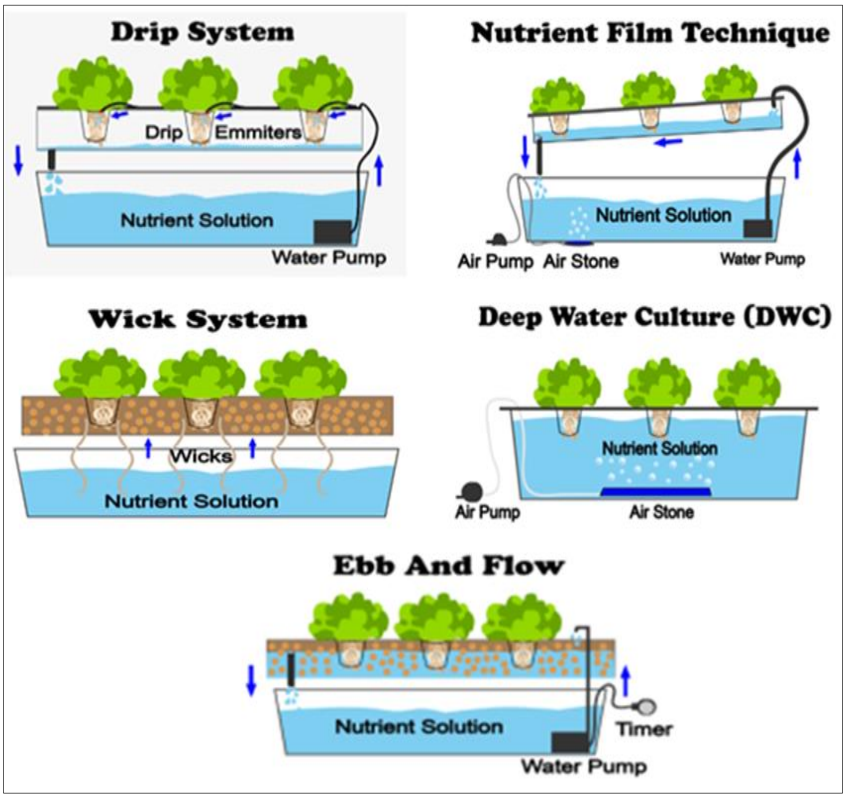

Fig 1: Different types of Hydroponic system

Table 2: Scientific studies concerning hydroponic system as a potential alternative to conventional cultivation system

S. No.	Paper Title	Country	Parameters Studied	Author
1.	Prediction and comparative analysis using ensemble classifier model on leafy vegetable growth rates in DWC and NFT smart hydroponic system	India	Plant growth dynamics	Srivani *et al.*, 2022 [112]
2.	Development of greenhouse with root dipping technique hydroponics structure to test the performance of jute mallow	Nigeria	Plant height, stem girth, leaf number, and yield.	Olubanjo *et al.*, 2021 [85]
3.	Controlled comparisons between soil and hydroponic systems reveal increased water use efficiency and higher lycopene and β-carotene contents in hydroponically grown tomatoes	UK	Water consumption, WUE, PWU, water transpired, stem growth, fresh weight, dry weight, fruit yield, lycopene, β-carotene, TSS, TAA	Verdoliva *et al.*, 2021 [122]
4.	Strategies for improved yield and water use efficiency of lettuce (*Lactuca sativa* L.) through simplified soilless cultivation under semi-arid climate	Brazil and Myanmar	Yield, leaf number, WUE, stomatal conductance	Nicola *et al.*, 2020 [84]
5.	Growth and yield response of Okra under root dipping hydroponic and conventional farming system	Nigeria	Plant height, stem girth, leaf number, root weight, and yield.	Olubanjo *et al.*, 2020 [85]
6.	Growth, production and water consumption of coriander grown under different recirculation intervals and nutrient solution depths in hydroponic channels	Brazil	Plant height, shoot fresh and dry matters, water consumption, WUE and visual quality	Silva *et al.*, 2020 [108]
7.	Evaluation of hydroponic systems for the cultivation of lettuce (*Lactuca sativa* L., var. Longifolia) and comparison with the protected soil based cultivation	India	Crop duration, photosynthetic parameters, crop growth parameters, crop quality para meters, Water consumption, economy	Majid *et al.*, 2021 [75]
8.	Evaluation of tropical tomato for growth, yield, nutrient and water use efficiency in recirculating hydroponic system	Ghana	WUE, NUE, plant growth, dry matter, fruit yield and quality	Ayarna *et al.*, 2020 [9]
9.	Tomato production through vine cutting technology in hydroponics system	Nigeria	Shoot formation, number of fruits, fruit weight	Ossai *et al.*, 2020 [87]
10.	Evaluation of hydroponic cultivation techniques as a supplement to conventional methods of farming	India	Germination rate, plant vigour, root morpho-anatomy, pigment contents, yield	Gurung *et al.*, 2019 [50]

Aeroponics

The word "aeroponics" is originated from the Greek terms aer (air) and ponos (labour). Plants are cultivated inside an air or mist atmosphere without using any aggregate medium, however, an assistance of artificial support is used to sustain the plant growth (figure 2) (Osvald *et al.*, 2001) [88]. As a result, it varies from both conventional hydroponics and aquaponics. The primary notion of aeroponics is to cultivate plants in a protected atmosphere by delivering a nutrient solution in a mist or atomized form with the help of nozzles and foggers (Mbiyu *et al.*, 2012) [78] and a film of nutrient is formed on the roots from where the roots absorb nutrient for their growth. The precise character of atomization spray frequency and duration enables the quantification of nutrient absorption levels within the plant throughout under various conditions. Rather than a continuous misting, the atomization spray gives an occasional sprinkle of nutrients to plant roots periodically for a specific duration (Lakhair *et al.*, 2018) [66]. Numerous studies have found that aeroponics is an efficient plant cultivation technology (Peterson and Krueger, 1988) [89], requires minimum water while providing an ideal condition for the growth of plants (Buer *et al.*, 1996) [19]. Aeroponics is a high-tech kind of hydroponic system that is classed as a closed system of soilless growing. This is a technique where plants are supported by plastic or polystyrene panels and positioned horizontally at the top of the growing container. These panels are typically comprised of inert substances like plastic, steel coated with plastic film etc. to suspend the root system (Maucieri *et al.*, 2019) [76]. The controlled parameters are equal nutrient levels, EC, pH, temperature, humidity, light intensity, atomization rate, atomization spray duration, atomization interval, and availability of oxygen (Lakhair *et al.*, 2018) [66]. Aeroponics could be a good approach for growing potato minitubers and it was discovered that limiting nutrition delivery during the stolon growth stage substantially boosts activity of root, limits stolon growth, and eventually triggers tuber initiation (Chang *et al.*, 2012) [22]. Therefore, nontuberizing conditions including warm conditions and delayed cultivars promote the employment of nutrient interruption approach. This system consists of three frameworks; the first is high pressure, which does not typically utilize a water pump, following by second known as "soakaponics", which is a low-pressure framework using standard water pumps to pour out the sprinklers (mister heads). The third framework consists of ultrasonic foggers that produce a mist (Domingues *et al.*, 2012) [31]. Hence, to mist the growing roots, various types of nozzles are used such as ultrasonic atomization foggers, high-pressure atomization nozzle and pressurized airless nozzles. An automated system maintains and controls static pressure of 60-90 Psi (Liu *et al.*, 2018) [72]. The spray span will be between 30-60 seconds; depending on the type of crop, cultivation period, plant growth stage and time. Aeroponics has a distinct advantage of promptly eliminating problematic plants from the support structure without disturbing or contaminating the neighboring plants. This approach is mainly suitable for small horticultural crops and has not been widely employed due to its high investment and management costs (Rakocy, 2012) [91]. However, the research revealed that crops cultivated in an aeroponic system have more production and comparable phenolics, flavonoids, and antioxidant characteristics than crops cultivated in soil (Chandra *et al.*, 2014) [21]. All herbs grown in aeroponics had the highest vitamin C content, whereas Holy Basil and Perilla grown in the substrate had the highest essential oil concentration (Bohme and Pinker, 2014) [18]. Aeroponics can outperform regular agriculture in terms of yield. As a result, it has the ability to generate more revenue and minimize the cost of producing quality seed, rendering widely accessible to growers in underdeveloped nations. NASA has financed exploration and innovation of sophisticated technologies to optimize aeroponic efficiency and minimize maintenance costs. This method is utilized as research tool and is appropriate for studying root morphology. Aeroponics has also revolutionized plant cloning from cuttings, since numerous plants were considered difficult to propagate; sensitive to bacterial infection became easier as it provides a highly aerated environment surrounding the root, resulting in good root hair formation. The global market was worth of $578.70 million in 2018 and is expected to touch $3.53 billion by 2026, increasing at a CAGR of 25.60% (Global Opportunity Analysis, 2019) [44]. Therefore, the global population explosion and spike in acceptance of controlled agriculture is likely to generate significant aeroponics market opportunities. Table 3 summarizes some of the studies that have been conducted in light of the significance of aeroponics.

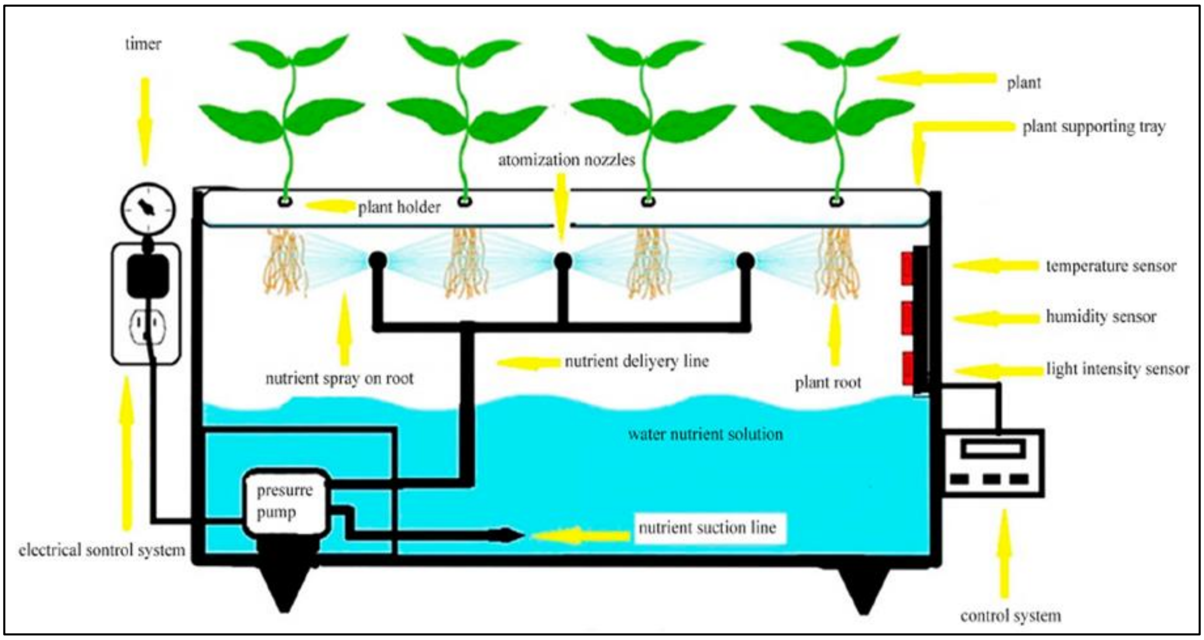

Fig 2: Aeroponics plant growing system with computer controlled techniques. (Source: Lakhair *et al.*, 2018) [66]

Table 3: Scientific studies concerning aeroponic system as a potential sustainable approach to conventional cultivation system

S. No.	Paper Title	Country	Parameters Studied	Author
1.	Growth and production of potato mini tubers (*Solanum tuberosum* L.) in the aeroponic system by root zone treatment and concentration of leaf-fertilizer	Indonesia	Growth and yield of mini tubers	Lhokitasari *et al.*, 2022 [71]
2.	A comparative LCA of aeroponic, hydroponic and soil cultivations of bioactive substance producing plants	Czech Republic	Content of bioactive substances, caffeine and theobromine contents, biomass yield, flavonoids	Wimmerova *et al.*, 2022 [125]
3.	Aeroponic evaluation identifies variation in Indian potato varieties for root morphology, nitrogen use efficiency parameters and yield traits	India	Root system architecture, plant height, leaf area, root and shoot dry weight, tuber traits and NUE parameters	Tiwari *et al.*, 2022 [116]
4.	The response of different potato cultivars to plant growth promting rhizobacteria (PGPRs) and chemical fertilizers in aeroponic culture conditions	Iran	Number and weight of min tuber, number of stolon, number of days up to tuberization, plant height, length of stolon	Nasiri *et al.*, 2022 [82]
5.	Exogenous salicylic acid improves photosynthetic pigments and morphological traits of four medicinal plants in an aeroponic system	Iran	Chlorophyll, carotenoid, plant height, root length, root volume, number of leaves, root fresh weight, root dry weight, shoot fresh weight, shoot dry weight	Mohit *et al.*, 2021 [79]
6.	Yield, characterization and possible exploitation of *Cannabis Sativa* L. roots grown under aeroponics cultivation	Italy	Plant growth and root bioactives (β-sitosterol, stigmasterol, campesterol, friedelin and epi-friedelanol)	Ferrini *et al.*, 2021 [38]
7.	Sensor based nutrient recirculation for aeroponic lettuce cultivation	Republic of Korea	Nutrient solution requirement and environmental pollutions	Chowdhury *et al.*, 2021 [24]
8.	Growth, yield and dormancy of aeroponically produced potato minitubers as a function of planting density and harvesting date	Brazil	Growth and yield of potato, effect of harvesting date and planting densities, number of stem, leaves, number and fresh weight of mini tubers	Balena *et al.*, 2021 [12]
9.	Potato production under different soilless systems	Egypt	Plant height, root length, number of leaves, stem diameter, leaf area, leaf length and potato yield	Khater, 2021 [63]
10.	Comparison of aeroponics and conventional potato mini tuber production systems at different plant densities	Turkey	Mini tuber production and yield	Çalışkan *et al.*, 2020 [20]

Aquaponics system

Aquaponics is a type of soilless culture where aquaculture in integrated with hydroponics for the purpose of producing both fish and vegetables in a synergistic environment (Rakocy, 2007) [93], where the nutritious fish water is supplied to hydroponic system and nitrifying bacteria transform ammonia into nitrates. The closed circulation system leads accumulation of aquatic effluents, arising from leftover feed or rearing animals such as fish, which in turn becomes hazardous to aquatic animals in high proportion; however, it contains nutrients required for plant growth. Hence, a pump is utilized to extract the water from the fish tank and deliver to the plant growing container through a biofilter where nitrifying bacteria can grow and toxic compounds are broken down. The beneficial bacteria like *Nitrosomonas sp.* and *Nitrobacter sp.* convert ammonia to nitrites and nitrites are converted to nitrates through metabolic process, respectively (Rakocy *et al.*, 2016) [92]. This ammonia conversion is amongst the significant activities in an aquaponic system since it minimizes the toxins for fish and permits the associated nitrate compounds to be assimilated for plant sustenance. The water is then cleansed and oxygenated before being returned to the aquaculture section, and the cycle continues. Many plants are suitable for aquaponics however it depends on the nutrient requirement of the plants. Green leafy vegetables having low to moderate nutritional demands thrive in less fish density and other plants with high nutrient requirement needs greater fish densities. There are different types of fishes that can be widely cultivated along with plants and they are classified as air-breathing and water breathing fish. Some of the air-breathing fishes are Anabas, Pangasius and gourami. Water breathing fishes are Tilapia, Red-bellied natter, rohu, mrigal and catla. Even ornamental fishes can be grown in an aquaponics system and high yield can be obtained from both fish and plants (Azad *et al.*, 2016) [10]. This aquaponics system can ensure food security in urban area by cultivating vegetables where space is not sufficient and also where scarcity of fertile land, soil degradation, are and lack of freshwater and problematic soil (Bindraban *et al.*, 2012; Klinger and Naylor, 2012) [16, 64]. Aquaculture can be effectively combined with three systems of hydroponics such as Deep-Water System, Nutrient Film Technique, flood and drain system, among these different systems DWC and NFT are the most widely used aquaponics system (Maharana and Koul, 2011) [74]. India, Israel, China and Africa are the emerging aquaponic leading nations (Singh and Singh, 2012) [110]. The global market value of this system valued at $662.49 million in 2019 and is projected to reach a market size of $1.29 billion in 2026 with a CAGR 12.5% (Global Aquaponics Market, Forecasts, 2021) [42].

Growing Medium and its types

The solid media culture is a medium other than soil which is inert and organic or inorganic material to support the plant growth which can be in different form. The media used must have high water holding capacity, porosity and various other properties leading to appropriate nutrition solution supply, proper oxygenation of roots to keep plants healthy. The quality of media must be greatly maintained to ensure good growth of seedlings. Different media is used to cultivate the plants since these media types has better physical properties with supplied nutrition to sustain plant growth and enable the efficient usage of resources. There are various mediums used such as coco coir, hydroton, perlite, vermiculite, peat moss, saw dust, rock wool, coarse sand etc. to sustain plant growth (Farhan *et al.*, 2018, see for review) [73]. These mediums are versatile in soilless production having excellent moisture and nutrient holding ability, good aeration, and easy exchange of oxygen. In addition, vermiculite has abundant amount of potassium and magnesium and is also rot resistant, helps to improve soil structure. Furthermore, some of the medium used are impervious to microbiological degradation, however, are far pricey than other material and are not interchangeable with other insulation material. Therefore, different methods adopted to use these growing mediums for crop production are, hanging bag technique, grow bag technique, trough or trench technique and pot technique. There are numerous studies confirming the use of growth media influence on plant growth and nutrition and eventually on the agricultural output. Some of the studies are mentioned in table 8 concerning the use of growth media.

Table 4: Scientific studies concerning aquaponic system as an efficient alternative to conventional soil based system.

S. No.	Paper Title	Country	Parameters Studied	Author
1.	Fish feeds in aquaponics and beyond: A novel concept to evaluate protein sources in diets for circular multitrophic food production systems	Germany	Nutrient cycling, circular multitrophic food production system, nutrient density	Shaw *et al.*, 2022 [106]
2.	Cost benefit analysis of soilless cultivation system in Tagaytay city, Philippines	Philippines	Cost-benefit analysis	Tality *et al.*, 2022 [114]
3.	Fish welfare in urban aquaponics: Effects of fertilizer for lettuce (Lactuca sativa L.) on some physiological stress indicators in Nile Tilapia (Oreochromis niloticus L.)	Spain	Fish production parameters, physiological indicators of fish stress and lettuce growth	Villarroel *et al.*, 2022 [123]
4.	Effect of biofertilizers on the integrated culture of genetically improved farmed Tilapia and green beans in aquaponics	Malaysia	Effect of commercial biofertilizers on production efficiency.	Saufie *et al.*, 2022 [102]
5.	Survival and growth rates of mangroves planted in vertical and horizontal aquaponic system in north Jakarta, Indonesia	Indonesia	Survival rate, correlation between physico-chemical environment parameters and survival and growth rates	Hilmi *et al.*, 2022 [55]
6.	Complementary nutrients in decoupled aquaponics enhances Basil performance	USA	Biomass, height, SPAD chlorophyll index, root:shoot biomass ratio	Rodgers *et al.*, 2022 [96]
7.	Structural and biophysical properties of whole leaf and root tissue and isolated cell walls of common green bean and tomato seedlings grown in an aquaponics system relative to soil-grown counterpart	USA	Comparing aquaponics and soil-grown counterpart and evaluate changes in structural components and energy producing components	Knoll and Marry, 2022 [65]
8.	Early production of strawberry in aquaponic systems using commercial hydroponic bands	Spain	Production and quality of strawberry	Fernández-Cabanás *et al.*, 2022 [39]
9.	Small-scale aquaponics and hydroponics systems: Pak Choy and spinach growth rate comparison	Malaysia	Quality, germination time, yield,	Lynn *et al.*, 2022 [73]
10.	Basil, Ocimum basolicum, yield in northern latitudinal aquaponic growing conditions	USA	Yield	Abbey *et al.*, 2021 [1]

Table 5: Scientific studies regarding the different growth media used in soilless farming

S. No.	Paper Title	Country	Parameters studied	Author
1.	Effect of different growing media on growth and yield of leafy vegetables in nutrient film technique hydroponics system	Nepal	Growth and yield	Chhetri *et al.*, 2022 [23]
2.	The effect of different growing media on physical morphology of Rockmelon (Cucumis Melo Linn cv. Glamour) seedling	Malaysia	Plant height, number of leaves, total leaf area and stem girth	Rauf *et al.*, 2022 [95]
3.	Soilless tomato production: Effects of hemp fiber and rock wool growing media on yield, secondary metabolites, substrate characteristics and greenhouse gas emissions	Germany	Leaf area, plant height, yields and fruit quality.	Nerlich *et al.*, 2022 [83]
4.	Non-composted chinaberry (Melia azedarach L.) sawdust mixtures as growth medium for okra (Abelmoschus esculentus (L.) Moench)	Pakistan	Growth, seed germination, leaf area, chlorophyll content, plant biomass, number of pods per plant, dry weight	Yasin *et al.*, 2022 [126]
5.	Conception and development of recycled raw materials (coconut fiber and bagasse)- based substrates enriched with soil microorganisms (Arbiscular Mycorrhizal Fungi, Trichoderma spp. And Pseudomonas spp.) for the soilless cultivation of tomato (S. lycopersicum)	France	Tomato production, plant performance, biotic and abiotic stress.	Masquelier *et al.*, 2022 [77]
6.	Effects of growing substrate, mode of nutrient supply, and saffron corm size on flowering, growth, photosynthetic competence, and cormlet formation in hydroponics	Egypt	Flowering traits, growth parameters, photosynthetic rate and stomatal conductance, yield	Dewir *et al.*, 2022 [30]
7.	The impact of different growth media and ammonium-nitrate ratio on yield and nitrate accumulation in lettuce (Lactuca sativa var. longifolia)	Turkey	NO_3^- accumulation, yield and growth attributes	SöYlemez, 2021 [111]
8.	Nursery production of *Pinus engelmannii* Carr. with substrates based on fresh sawdust	Mexico	Substrate combinations that favour the quality of *Pinus engelmannii* Carr.	González-Orozco *et al.*, 2018 [46]
9.	Sawdust and bark-based substrates for soilless strawberry production: irrigation and electrical conductivity management	Canada	Productivity potential	Depardieu *et al.*, 2016 [29]
10.	Impacts of the substrate medium on tomato yield and fruit quality in soilless cultivation	Greece	Yield, fruit quality parameters	Tzortzakis and Economakis, 2008 [119]

Nutrient solution for the soilless system

The aqueous solution containing nutrients needed for plant growth and development along with air (oxygen) and water. Currently, 17 nutrient elements regarded for their essential growth are carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, copper, zinc, manganese, molybdenum, boron, chlorine and nickel (Salisbury and Ross, 1992) [98]. Elements like Carbon and Oxygen are obtained from the atmosphere (Trejo-Téllez and Gómez-Merino, 2012) [117]. The nutrient solution is prepared by dissolving inorganic salts in water, which dissipates as ions are absorbed by the plant root system. The level of nutrients in the solution should be monitored regularly and the best time is between 6:00 and 8:00 am. The water and nutrient requirement varies every day based on the type of crop and age of the plant. This nutrient solution should be applied to the roots of the plant without wetting the foliage as it causes a scorching effect on leaves. Regularly around 20-50% of the nutrient solution in the hydroponic system has to be drained off and refilled with the new solution as it avoids the accumulation of toxic ions (Sardare and Admane, 2013) [101]. Table 6 presents the concentration of different nutrients used in soilless farming. Furthermore, optimum EC and pH for different crops has also been summarized in table 7.

Table 6: Commercially prefixed available nutrient solution and concentration ranges of essential mineral elements (Cooper, 1988; Steiner, 1966; Baudoin *et al*., 1990) [26, 113, 15]

Nutrient	Hoagland and Arnon (1938)	Hewitt (1966)	Cooper (1979)	Steiner (1984)
N	210 mg L^{-1}	168 mg L^{-1}	200-236 mg L^{-1}	168 mg L^{-1}
P	31 mg L^{-1}	41 mg L^{-1}	60 mg L^{-1}	31 mg L^{-1}
K	234 mg L^{-1}	156 mg L^{-1}	300 mg L^{-1}	273 mg L^{-1}
Ca	160 mg L^{-1}	160 mg L^{-1}	170-185 mg L^{-1}	180 mg L^{-1}
Mg	34 mg L^{-1}	36 mg L^{-1}	50 mg L^{-1}	48 mg L^{-1}
S	64 mg L^{-1}	48 mg L^{-1}	68 mg L^{-1}	336 mg L^{-1}
Fe	2.5 mg L^{-1}	2.8 mg L^{-1}	12 mg L^{-1}	2-4 mg L^{-1}
Cu	0.02 mg L^{-1}	0.064 mg L^{-1}	0.1 mg L^{-1}	0.02 mg L^{-1}
Zn	0.05 mg L^{-1}	0.065 mg L^{-1}	0.1 mg L^{-1}	0.11 mg L^{-1}
Mn	0.5 mg L^{-1}	0.54 mg L^{-1}	2.0 mg L^{-1}	0.62 mg L^{-1}
B	0.5 mg L^{-1}	0.54 mg L^{-1}	0.3 mg L^{-1}	0.44 mg L^{-1}
Mo	0.01 mg L^{-1}	0.004 mg L^{-1}	0.2 mg L^{-1}	-

Table 7: The optimum range of EC and pH values for vegetables grown in hydroponics crops (Sharma *et al.*, 2018) [105]

Crops	EC (dSm^{-1})	pH
Asparagus	1.4-1.8	6.0-6.8
Bean	2.0-4.0	6.0
Broccoli	2.8-3.5	6.0-6.8
Cabbage	2.5-3.0	6.5-7.0
Celery	1.8-2.4	6.5
Cucumber	1.7-2.0	5.0-5.5
Egg Plant	2.5-3.5	6.0
Leek	1.4-1.8	6.5-7.0
Lettuce	1.2-1.8	6.0-7.0
Pak Choi	1.5-2.0	7.0
Peppers	0.8-1.8	5.5-6.0
Parsley	1.8-2.2	6.0-6.5
Spinach	1.8-2.3	6.0-7.0
Tomato	2.0-4.0	6.0-6.5

Advantages and Disadvantages

Soilless farming is a prominent approach in today's world with numerous benefits over traditional cultivation system. It offers favorable environment to plants and provide a year round production with minimum usage of water and nutrients compared to conventional agriculture. Numerous studies on the subject have shown that soilless faming has potential to produce higher output than soil based cultivation. The controlled system of soilless farming also reduces biotic and abiotic stresses, thus sustain crop growth. The conservation of resources and ecological sustainability is amongst the profound advantages of soilless farming.

Despite several merits, it also has certain demerits including technical knowhow requirement to operate the system, higher initial investment, surveillance of various plant growth parameters (pH, EC, nutrient concentration etc.), and electricity requirement. Therefore, careful consideration is required before initiating soilless cultivation.

Conclusion and Future Thrust

Soilless farming is expanding across the globe to sustain the growing population, and like approaches provide numerous opportunities for producers and clients to produce quality vegetables boosted with bioactive components by replacing traditional farming. It is possible to cultivate various vegetables in places with less space and reduced water availability, so hydroponics can make a significant contribution in such areas. Besides, it can ignite and uplift the economic growth of a country by promoting innovative entrepreneurship. Furthermore, since it is a controlled system, it provides a year-round production. Therefore, low-cost soilless and other high-tech innovations must be developed in order to improve industrial soilless farming with lower investment and operational costs. In the future, studies on the subject may delve at specific methodologies and implementation of various sorts of soilless farms. Soilless cultivation methods include Hydroponic, Aeroponic and Aquaponic systems. For instance, rigorous study is needed to precisely quantify the benefits and drawbacks of various types of soilless farming and should further be checked to augment the adoption of these techniques in the long run. Soilless methods are also being considered for future space programmes which will pave avenue for space research and eventual habitation on Moon and Mars. In India, the adoption is increasing, however it is still in infancy and government should take initiation to encourage people for investing and adoption of these techniques by raising awareness, conducting educational seminars on the topic throughout country and must integrate in cities to generate year round supply of food for an increasing population.

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