Revolutionizing Agriculture: Sustainable Solutions for High-Yield Farming Using Vertical Hydroponics

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ARTICLE INFO

Article history:
Received: 6 July 2023
Revised: 10 August 2023
Accepted: 24 August 2023

Keywords:
Cultivation methods
Hydroponics
Vertical farming

ABSTRACT

Among all the existing cultivation methods, hydroponics has emerged to be the best method of cultivation for herbaceous plants. Several factors like less expensive setup, low dependency on natural resources, energy efficiency, ease of setup and maintenance, minimal requirement of technical knowledge, etc., determine the hydroponic method to be the best one among all the other vertical farming methods. Along with being extremely simple to establish and maintain, hydroponics also ensures multiple times higher production in better quality and quantity. Damage to agricultural produce caused due to pests, incorrect selection of cultivation medium, increased use of fertilizers for cultivation, and incorrect crop selection for a given climatic condition and soil type, is also overcome in the hydroponic process of cultivation. Another major reason for the hydroponic method to outperform the other vertical farming methods is that it can be implemented in five different types of setups where each crop shows different growth responses. The most suitable hydroponic setup has been identified for different plants, according to their growth requirements, to ensure enhanced growth. Not only the food demands are fulfilled using these methods qualitatively, but also the environmental sustainability and improved economy of any nation are effectively ensured.

1. INTRODUCTION

With the advent and expanse of urban civilization, the traditional soil-based agricultural processes are found to encounter many challenges. Because of the advantages of urbanization in fields of technology, innovation, and increased diverse employment options, the majority of the rural population is shifting to the urban localities and agricultural practices are compromised [1]. The most significant aftereffect of these issues is the adverse effect on the environment and the worldwide economy. Coping with the rising food demands of society with traditional cultivation methods is the greatest issue of today's world. Some of the challenges faced in traditional agricultural cultivation methods are [2]:

- Lack of land for cultivation.
- Damage caused by disease-causing organisms or pests.
- Abrupt and unpredictable climatic changes.
- Poor drainage.
- Depleting soil quality and poor nutrient content.
- Soil erosion.
- Depleting natural resources.
- Use of chemicals, etc.

All these reasons sum up to cause the immediate emergence of alternative soilless farming techniques that can suffice the food demands quantitatively as well as qualitatively [3-4]. There are many outstanding merits of the alternative cultivation methods like ensured multiple times better yield in minimal vegetation period, no dependency on soil and natural resources, reduced damage due to pests, etc. Many vertical farming techniques have emerged in the past few decades which help in the cultivation of crops without soil and without any dependency on any natural resource or environmental condition. These methods facilitate the cultivation in vertically stacked layers which use lesser space to produce multiple times increased vegetation [5].

Apart from making the cultivation process soilless, it is also important to provide all the necessary climatic and nutrient requirements of the plants externally. This method is known as Controlled Environmental Agriculture (CEA).

CEA refers to the process of controlling and maintaining all the environmental conditions required for the plants to grow in the best manner. It is a modern approach of precision farming where a controlled growing environment for plants is ensured in an enclosed structure for its better growth, and improved qualitative yield. Apart from ensuring minimum water and pesticide usage, CEA also efficiently addresses the challenges faced in primitive agricultural processes, like pests, plant diseases, dependency on natural resources, etc. This way CEA helps in making the farming method independent of the natural resources as well as climatic conditions [6, 7].

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CEA comprises some key elements like controlled irrigation, climate, nutrient distribution, pests, and disease control, and automatic monitoring systems.

Some of the key benefits of CEA can be enlisted as increased qualitative and quantitative yield, reduced vegetation cycle, year-round yield, resource efficiency, and ease of flexibility of location.

Though CEA offers numerous advantages, it also comes with challenges, such as initial setup costs, energy consumption for climate control and artificial lighting, and the need for technical expertise to manage the systems effectively. However, as technology advances and economies of scale improve, controlled environment agriculture is expected to play an increasingly significant role in meeting the growing demand for sustainable and reliable food production.

This further reduces agricultural losses to a great extent. These vertical farming techniques may be operated either manually or automatically. When the system is monitored and maintained manually and all the remedial measures are carried out by the farm owner, manually, the vertical farming system is manual. The use of IoTs, on the other hand, makes the vertical farming system smart and more advantageous [8]. The specific sensors are deployed according to the parameters that need to be monitored in the vertical farming system. Each sensor is set with a range of parametric values that are needed by the plant to grow. The real-time values from the sensors are collected and sent to the cloud for analysis. The sensor values violating the preset parametric ranges are identified and the corresponding actuators in the system are activated to maintain the values in a range. This way all the required nutrients and climatic conditions are ensured to the plant growing environment and plant cultivation takes place in an increased quality and quantity throughout the year. This entire method of farming is termed smart precision farming [9]–[11].

The soilless vertical farming methods use either water or air as the basic cultivation mediums. Aeroponics, hydroponics, and aquaponics are the soilless smart precision vertical farming methods, out of which hydroponics outperforms the other two methods in terms of higher yields, low initial setup cost, low maintenance expenses, and ease of operation. A bibliometric analysis using the 'biblioshiny' tool in RStudio is carried out to determine the best vertical farming method that is trending in the past 10 years. CSV files related to aeroponics, hydroponics, and aquaponics are retrieved from the SCOPUS database and a tabular representation of the annual scientific production of all three vertical farming methods is obtained. Table 1 shows the research production trends of aeroponics, hydroponics, and aquaponics respectively.

Table 1. Number of SCOPUS-indexed research articles produced since 2013

Aeroponics		Hydroponics		Aquaponics	
Year	No. of articles	Year	No. of articles	Year	No. of articles
2013	14	2013	316	2013	11
2014	12	2014	320	2014	22
2015	7	2015	381	2015	25
2016	13	2016	438	2016	56
2017	19	2017	458	2017	79
2018	24	2018	554	2018	96
2019	23	2019	616	2019	148
2020	37	2020	690	2020	168
2021	43	2021	787	2021	182
2022	49	2022	766	2022	214
2023	26	2023	406	2023	88
Total	**267**	**Total**	**5732**	**Total**	**1089**

It is found that the total number of published articles on aeroponics, hydroponics, and aquaponics are 267, 5732, and 1089 respectively. Thus, it can be clearly stated that hydroponics outperforms the other two vertical farming methods in the past 10 years.

Hydroponics is the process of cultivating herbaceous plants in a nutrient-infused water medium. Fig. 1 shows a basic hydroponic setup [12]–[14].

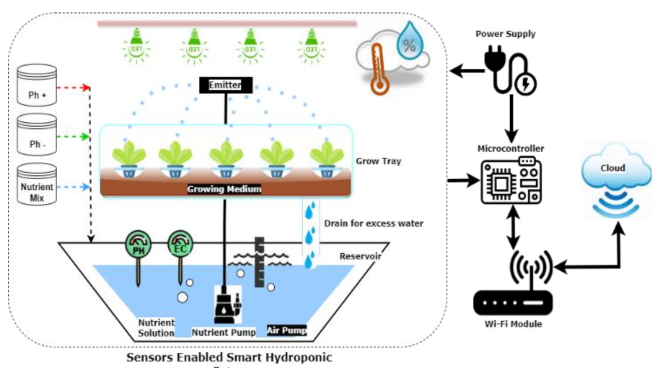

Fig. 1. The working of a sensor-enabled smart hydroponic setup

In a hydroponic cultivation method, the roots are immersed in the nutrient-mixed solution and the shoots are above the medium [15]. The nutrient content of the water is checked for the amount of nutrients in it and accordingly, the nutrients are added to the solution for the proper growth of the plant. The parameters like the potential of Hydrogen (pH), electrical conductivity (EC), total dissolved solids (TDS), etc.

are monitored and maintained continuously to provide optimal conditions for the proper growth of the plant [16, 17]. The cultivation process is done in a closed setup where the environmental factors like temperature, humidity, light intensity, etc. are maintained within their limits. For this process, each of the factors is monitored with the help of dedicated sensors. Every time the plants are planted in this setup, the agronomic values and requirements are studied and the sensors are preset with the desired ranges of values. The sensor values are monitored and maintained in those preset ranges to ensure the best yield for the plants [18]–[21]. Many hardware actuators like exhaust fans, coolers, mist sprays, water and nutrient pumps, etc. are also connected to the smart hydroponic system which is activated whenever any parametric value goes out of range. This way precise agricultural conditions are supplied to the growing environment of plants, which is called precision farming, and the entire setup is known as smart precision farming in a hydroponic setup [22, 23].

1.1. Advantages and disadvantages of hydroponics

Although hydroponic cultivation offers numerous possibilities for food cultivation, it is not a panacea. Like any alternate cultivation technique, it has its benefits and drawbacks. For a thorough analysis of the method, a detailed and extensive review is necessary to identify the areas where the scope of development is still possible through advantageous technological impact.

1.1.1. Advantages

- **Space efficiency and ubiquity –** Cultivation of food, in a CEA, almost anywhere, is made possible through hydroponics [24]. The scalability of the hydroponic method of cultivation is increased further by implementing it in various setups and devising vertical arrangements for increased agricultural produce according to the plant type taken into consideration [25, 26].
- **Assurance of enhanced quality along with the quantity of the produce –** In traditional substrate cultivation methods, one of the major necessities to preserving soil fertility is crop rotation. Hydroponic cultivation methods remove this constraint also. Hydroponic plants can be cultivated as many times as needed. This in turn reduces the cultivation cycle of the crop along with increasing its yield per cycle. The qualitative yield and better growth response are also ensured due to its administered plant physiological and nutritional requirements [27, 28].
- **Enhanced sustainability –** Since the nutrient solution is recycled as the cultivation medium, many factors like the evaporation of water or pollution are minimized. Though the cultivation is entirely carried out in a water medium, the water consumption in the case of hydroponic cultivation is almost 30% of the quantity of water consumed in substrate cultivation methods. CEA again plays the most important role in ensuring protection against plant diseases, thus reducing the need of using chemical pesticides [26, 29].
- **Ease of operation and economy –** Hydroponic setups are simpler to assemble and set up as compared to traditional agricultural practices. The conventional practices involve many effort–intensive preparations before cultivation, including the cost of heavy machinery and dedicated equipment for plowing, sowing, irrigating, monitoring, management of pesticides and fertilizers, etc. Hydroponic cultivation eliminates any such dependency on equipment or climatic conditions, or natural resources. It is simpler to manage and increased production is guaranteed [22, 29].

1.1.2. Disadvantages

- **High initial cost –** Though hydroponic setups are easy to compile and maintain, the initial cost of establishing the setup causes a hindrance to the complete acceptance of the process. The setup consists of various components, devices, and raw materials that cause a considerable initial expense [30]–[31].
- **Requirement of skilled labor –** The setup, operation, and maintenance of hydroponic farming requires highly skilled people. Technical knowledge of using and operating sophisticated control and smart devices is a must, apart from the knowledge of farming and plant-specific details, especially in the case of large-scale hydroponic setups [32].
- **Energy consumption –** Because all the necessary growing conditions needed by the plants are provided externally and a controlled environment is maintained in the setup, the overall energy consumption is increased multiple times as compared to the substrate cultivation methods [33, 34].
- **Increased pollution –** Severe environmental hazards may be caused if the residual nutrients, rich in nitrates and phosphorous, are not properly disposed of. This may lead to excessive accumulation of effluents and the growth of microorganisms like algae in water bodies, causing serious environmental problems [35]–[37].

One of the major reasons for hydroponics to excel among all the other precision farming methods is its scalability. The hydroponic setup can be implemented in five different setups, namely Nutrient Film Technique (NFT), Deep Water Culture (DWC), Drip Technique, Wick Technique, Ebb, and Flow. Every plant responds differently in terms of growth when cultivated in different hydroponic setups [38]. So, the need to identify the best hydroponic method for each type of herbaceous plant has to be identified for more enhanced yield with optimized resource usage. The several advantages of hydroponic cultivation over the rest of the methods have made their mark in many nations worldwide [39].

This paper focuses on providing a systematic literature review of the hydroponic method of vertical farming for cultivating herbaceous plants, based on rigorous analysis of the experimental evidence gathered from the thorough evaluation of the available literature on the work done in this area. This also aims to assess the potential use of hydroponics as an alternative to traditional soil cultivation methods. This review was carried out by analyzing studies related to various types of hydroponic setups that are used in the cultivation of herbs. The authors have assessed the performance of various hydroponic vertical farming methods in different scenarios. The results of this study give a detailed preview of which hydroponic setup is best suited for which type of crop under which circumstances while offering other significant benefits over the existing methods of cultivation, in terms of lesser damage and better qualitative and quantitative yield, all year round. The hydroponic setup is implemented in various types of setups. All of those are discussed in this study with their respective advantages and disadvantages in different scenarios of cultivation.

The key contributions of the authors in carrying out the research in this manuscript can be summarized as: (1) studying the evolution of vertical farming techniques, and the importance of CEA; (2) discussion of hydroponics cultivation methods; (3) classification of hydroponic setup under various parameters along with their pros and cons; (4) detailed study about the various types of aggregates used in the hydroponic setups along with their properties, their advantages and disadvantages; followed by, (5) a list of suitable crops to be cultivated in hydroponics, and finally the conclusion summarizing the detailed analysis of hydroponic cultivation methods.

The organization of the manuscript can be summarized as Section 1 includes the introduction of the manuscript; Section 2 deals with the classifications of the hydroponic setups under various parameters; the pros and cons of various hydroponic setup are discussed elaborately in Section 3; Section 4 deals in the various types of aggregates that can be used in the hydroponic setups; Section 5 contains the various types of vegetables and their corresponding hydroponic technique; and finally the manuscript is concluded in section 6.

2. TYPES OF HYDROPONIC SETUPS

Hydroponic setups can be classified based on three parameters: based on mechanism, based on nutrient circulation method, and based on plantation setups. Fig. 2 shows the classifications of hydroponic setups based on various parameters.

2.1. Classification of hydroponics methods based on mechanism

Hydroponic setup can be broadly classified based on the mechanism as active and passive hydroponics.

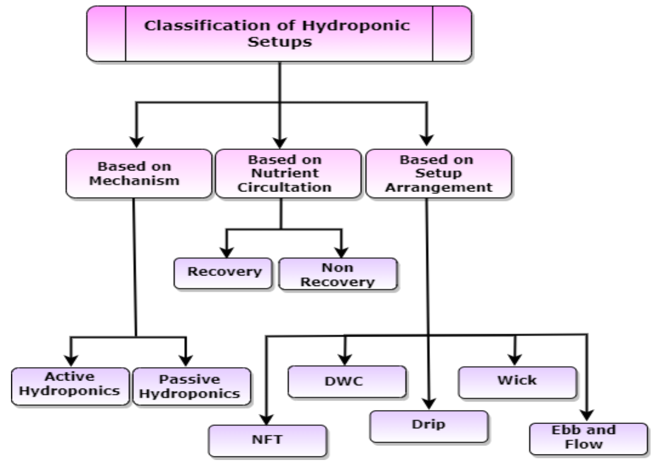

Fig. 2. Classifications of hydroponic setups according to various parameters.

2.1.1. Active hydroponics – the hydroponic process where no use of pumps or fans is to circulate the nutrient solution or maintain the temperature of the setup. The system relies on gravity for nutrient circulation to the plant roots. e.g., wick hydroponics [40, 41].

2.1.2. Passive hydroponics – the hydroponic setup where pumps are used to ensure proper and timely circulation of nutrient solution to the plant. e.g., NFT [42, 43].

2.2. Classification of hydroponics methods based on nutrient circulation

Another basis for the classification of hydroponic cultivation methods is the method of nutrient water circulation. These are called: Recovery and non-recovery hydroponics.

2.2.1. Recovery technique – if the nutrient mix is recirculated to the plants in the system, it is termed a ‘recovery method’. e.g., NFT [43].

2.2.2. Non-recovery technique – if the nutrient solution is not circulated to the plants, it is termed as ‘non-recovery hydroponics’. e.g., DWC [39].

2.3. Classification of hydroponics based on setups

There are five varied ways to set up a hydroponic cultivation system according to the requirement of the plant. They are NFT, DWC, Drip Technique, Wick Technique, and Ebb and Flow Technique.

2.3.1. Nutrient Film Technique (NFT)

An entirely water-based cultivation process, as the hydroponic method is, NFT consists of a dedicated setup consisting of grow tubes, water pumps, nutrient pumps, various sensors, actuators, water and nutrient reservoirs, etc. The plants are placed in perforated growing containers and put in the grow tubes [44]. The plants are placed in such a way that the roots are submerged in the nutrient solution and the shoots are above the tubes. The nutrient-rich solution is stored in the nutrient reservoir which is circulated through all the vertically stacked grow tubes containing plants, with the help of pumps [45]. The water is not allowed to stand and is flown through the roots continuously for a certain period and then collected back in the reservoir. Thus, the water is easily recycled. The solution is periodically checked for nutrient content and is maintained accordingly. One consideration while selecting plants to be cultivated in NFT hydroponics, is that it should be small so that it fits in the grow tubes easily. Fig. 3 illustrates an NFT hydroponic setup [46].

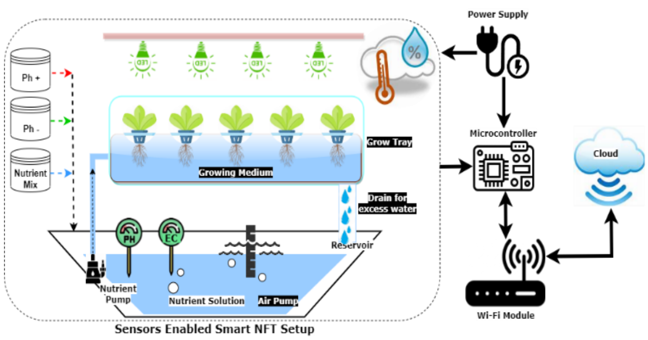

Fig. 3. The working of a smart NFT setup.

2.3.2. Deep Water Culture (DWC)

One of the simplest types of hydroponic setups is DWC. It does not involve any special technical setup. In this setup, the plant roots are fully immersed in the nutrient solution from which the roots absorb the required nutrients [47, 48]. The presence of tools like aerating stones ensures proper oxygenation of roots by diffusing air through the nutrient mix and producing oxygen bubbles. Fig. 4 illustrates a DWC hydroponic setup [49].

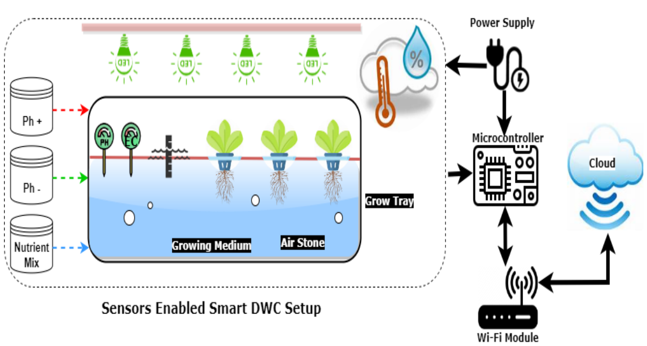

Fig. 4. The working of a smart DWC setup.

2.3.3. Drip System

A hydroponic setup where the user has full control over the amount of nutrient solution supplied to each of the plants. The supply of the solution can thereby be adjusted through the drip emitters, based on the plant type and the frequency of nutrient supply to them [50]. Ease of scalability is another advantage of the drip system of hydroponics. Fig. 5 illustrates a drip hydroponic setup [51].

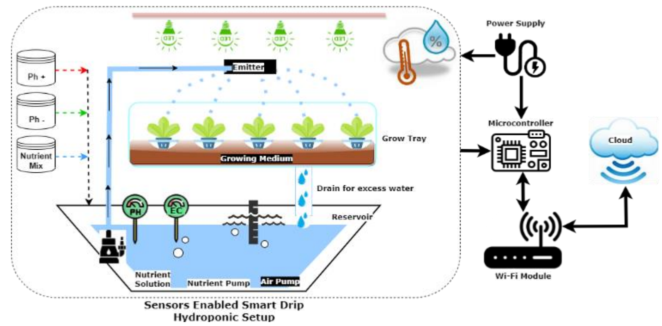

Fig. 5. A basic drip hydroponic setup.

2.3.4. Wick Technique

The Wick technique is a passive hydroponic system that does not require electricity, pumps, etc. It is also a non-recovery type because it does not involve recirculating the nutrient water back to the reservoir [52]. The plants are directly placed into a porous medium with nylon wicks attached around the roots. The other end of the wick is immersed in the nutrient solution. The wicks then transfer the nutrient solution to the aggregate through their capillary action. The plant roots then take up the nutrients and grow [53]. Sand, vermiculite, and perlite are some generally used aggregates used in wick hydroponic systems. Fig. 6 illustrates a wick hydroponic setup.

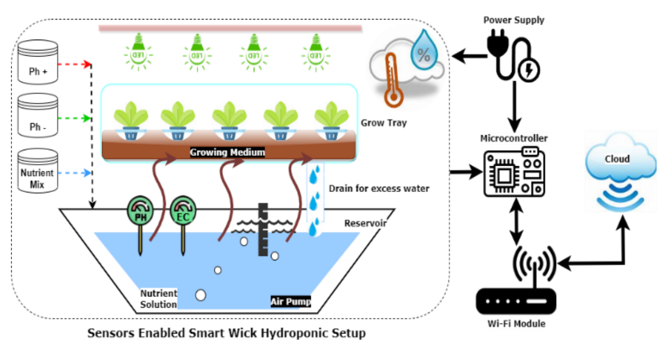

Fig. 6. The working of a smart wick hydroponic setup.

2.3.5. Ebb and Flow (Flood and Drain) System

Ebb and flow hydroponic systems, also known as flood and drain systems, gain popularity due to ease of design, maintenance, and feasibility in commercial as well as domestic ventures. This setup involves cultivation in the grow tubes or growing trays with high edges [54]. The grow trays are filled with growing medium to hold the plants in place. The nutrient solution is pumped in the grow trays till it reaches a specific height where the roots are properly dipped in the solution. After a specific period of a maximum of five minutes, the nutrient solution is drained back into the reservoir and the solution is recirculated. The circulation time of nutrient solution can be monitored using a timer, whereas the amount of solution circulated depends upon factors like tray size, number of plants grown, size of the plants, nature of the aggregate used, etc. [55]. Coconut coir mixed with perlite is found to be the most ideal aggregate for a hydroponic system. A mix of coco coir and perlite is ideal for ebb and flow hydroponic systems. Fig. 7 illustrates an ebb and flow hydroponic setup [56].

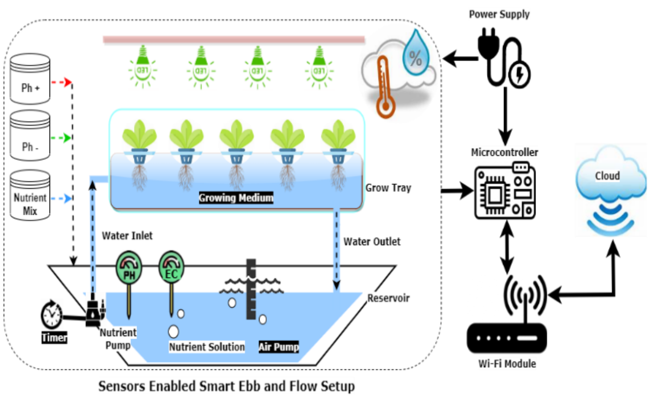

Fig. 7. The working of a smart ebb and flow hydroponic setup

3. ADVANTAGES AND DISADVANTAGES OF VARIOUS HYDROPONIC SETUPS

The selection of hydroponic setups depends on their advantages and disadvantages, and the types of plants they support. Table 2 is the tabular representation of the advantages and disadvantages of various hydroponic setups.

4. AGGREGATES USED IN HYDROPONIC SYSTEMS

Aggregates or substrates are the physical mediums that support plants by their stems and help keep them under required growing conditions. They are an important component of a hydroponic system. The mediums also provide an aseptic growing environment with adequate nutrient supply, drainage, and proper oxygenation or aeration. Some examples of hydroponic media are rock wool, vermiculite, coco coir, clay pellets, gravel, sand, and peat moss [44, 46, 58].

The determination of aggregate for use in hydroponic setups depends on several factors. Some of them are:

- Cost price
- Ease of use
- Compatibility with the hydroponic setup – large or small scale

Table 3 represents a compendium of typically used materials that are used as substrates along with their advantages and disadvantages. A variety of inert media or aggregates is available for use in hydroponic systems.

Table 2. Advantages and disadvantages of various hydroponic setups

NFT hydroponic setup [57]–[59]	
Advantages	**Disadvantages**
• Convenient for small and medium-sized plants. • Compatible with cultivating many plants simultaneously. • No growing medium is needed.	• Useful for plants with small root lengths. • Does not support massive plants.
DWC hydroponic setup [60]–[62]	
Advantages	**Disadvantages**
• Ensures complete submersion of roots. • Ease of nutrient absorption. • Easy to set up. • Supports almost all types of plants. • Faster growth of plants.	• Possibility of root disease. • Consistent maintenance is required.
Drip hydroponic setup [63]–[65]	
Advantages	**Disadvantages**
• Can be altered easily. • Reuse of nutrients. • Perfect for specific plant types. • Supports bigger plats also.	• pH needs to be monitored constantly. • Nutrient levels must be maintained. • Possibility of root diseases.
Wick System hydroponic setup [52, 53]	
Advantages	**Disadvantages**
• Ease of design. • Inexpensive. • No electrical equipment or moving parts are needed. • Convenient for experimental trials. • Uses simple equipment.	• Uneven distribution of nutrients. • Does not support large plants. • Poor nutrition in plants.
Ebb and Flow hydroponic setup [55, 56]	
Advantages	**Disadvantages**
• Easy and cheap to maintain. • Suitable for a wide variety of plants. • Most beneficial for root vegetables.	• Does not support large plants. • Depends entirely upon pumps. • Requires ample space

Table 3. Types of aggregates, their properties, advantages, and disadvantages

Properties	Advantages	Disadvantages
1. Rockwool [66, 67]		
Properties	**Advantages**	**Disadvantages**
• Fibrous cubes or slabs, are made by melting rocks. • It does not spike pH. • Has to be soaked overnight before use, to disperse the bonding agents. • Density – 80 kg/m3.	• Capable of holding a substantial amount of water. • Retains air and ensures optimal oxygenation to the plants for better growth. • Facilitates continuous and sustained drainage. • Inert and sterile.	• Does not decompose. • Difficult to dispose of.
2. Vermiculite or Perlite [68, 69]		
Properties	**Advantages**	**Disadvantages**
• Made out of stone. • It is derived from volcanic rocks. • Perlite density is 90 kg/m3. • Vermiculite is derived from mica. • Vermiculite density is 80 kg/m3.	• Very lightweight. • Easily manageable. • Ideal for beginners. • Improve aeration and drainage. • Best suited for wick hydroponics. • Non-reactive and neutral pH.	• It does not retain water and dries up quickly. • Not convenient for setups with running water. • Vermiculite or perlite dust is hazardous to health.
3. Coconut Coir or Coco Coir or Coconut fiber [70, 71]		
Properties	**Advantages**	**Disadvantages**
• Organic material. • Derived from waste coconut husks. • It Outperforms rock wool and perlite in versatility. • Many variants are available. • The density is 60 kg/m3. • pH range is 5 to 8.	• Absorbs and retains plenty of water. • Has a better air capacity than perlite or vermiculite and holds plenty of oxygen. • Entirely organic. • Does not affect pH. • It can be recycled. • Non-reactive and does not affect solution for plants.	• Some variants are expensive. • May need leaching.
4. Clay Pellets [72, 73]		
Properties	**Advantages**	**Disadvantages**
• Another popular aggregate for hydroponics. • 1 – 18 mm big. • Expands when soaked in water. • Tiny air pockets in each pellet. • Recommended for Ebb and Flow hydroponics.	• Beneficial for the ebb and flow systems. • Easy to maintain. • Can be reused after disinfection. • Facilitates perfect drainage. • Easy to flush and dispose of. • Reusable.	• Poor water retention. • Easily dies up. • Absorb salt. • Expensive.
5. Gravel [74]		
Properties	**Advantages**	**Disadvantages**
• Beneficial for systems needing frequent watering.	• Inexpensive. • Robust and heavy-duty. • Reusable • Provides aeration for roots. • Readily and easily available everywhere.	• Does not absorb water. • Requires frequent watering.
6. Sand [75]		
Properties	**Advantages**	**Disadvantages**
• One of the original aggregates in hydroponics. • Least used hydroponic aggregate.	• Budget-friendly. • Heavy duty. • Readily and easily available.	• Packs tightly thus providing poor oxygenation. • Does not retain moisture. • Not ideal for many plants.
7. Peat Moss [76]		
Properties	**Advantages**	**Disadvantages**
• Entirely natural. • Sponge-like – retains water. • Useful in large net ports.	• Efficiently absorbs water. • Enhanced water retention. • Organic. • Easy to use. • Better aeration for root growth. • Inert.	• Decomposes easily • Needs frequent replacement. • Clogs hydroponic setups, pumps, and emitters. • Dissolves easily in water – causes root diseases

Several important physiological, biological, chemical, and environmental sustainability factors play an important role when it comes to the selection of aggregate for any hydroponic setup [66]–[68]. Some of the most relevant ones are:

• **Inertness:** inertness of any substrate or aggregate may be classified into two categories –

> ***Chemical inertness –*** where the aggregates comprise materials that do not chemically react with the other chemical compounds present in the

hydroponic setup, thereby causing no change in the composition [66, 67].

Biological inertness – where the aggregates are unreactive with the micro-organisms in the system and they create an unfavorable condition for any kind of biological activity. This type of aggregates prevents the spread of diseases, and malnutrition kind of detrimental effects on plants [76].

- **Oxygenation:** the substrate must be able to facilitate the oxygen intake by the roots when they are immersed in the nutrient-mixed water [66, 68, 70].
- **Porosity**: the property of the aggregate whereby the nutrient availability to the plants is facilitated to carry out various processes like photosynthesis, breathing, and transpiration [76].
- **Capillarity**: the property whereby the aggregate takes in nutrients and distributes them throughout the plant body [68].
- **Environmental sustainability**: the environmental, economic, and social feasibility of the aggregate has to be analyzed. The aggregates composed of organic and bio-degradable materials, are more ecological and preferred over the others [70, 72].

5. SUITABLE CROPS CORRESPONDING TO VARIOUS HYDROPONIC SETUPS

Almost all kinds of herbaceous plants are found suitable for cultivation in the hydroponic medium. Despite that, the most suitable hydroponic setup has to be identified to obtain the best possible yield for any herbaceous plant. Table 4 encapsulates several crops and their corresponding compatible hydroponic farming techniques.

Table 4. Most suitable plants to grow by hydroponics

Category	**Compatible hydroponic setups**		
	NFT	**Drip Technique**	**DWC**
Fruit Vegetables [77, 78]	Cucumber	Cucumber	
	Tomato	Watermelon	
	Zucchini	Tomato	
		Zucchini	
		Egg Plant	
Tuber vegetables [79]		Potato	
		Sweet Potato	
Flower vegetables [80]	Cauliflower	Cauliflower	
	Broccoli	Broccoli	
	Huauzontle		Huauzontle
		Sweet corn	
Pulses type [59, 81]		Peas	
		Beans	
Root vegetables [82]		Beetroot	
	Turnip		
		Radish	
		Carrot	
Stem vegetables [83]	Asparagus		Asparagus
		Swede	
Leafy vegetables [84, 85]	Lettuce		Lettuce
	Spinach		Spinach
	Coriander	Coriander	Coriander
	Parsley		Parsley
	Celery		Celery
	Cabbage		Cabbage

6. CONCLUSION

Hydroponics ensures enhanced yield of plants in all aspects but the cultivation of plants in the most suitable hydroponic setup enhances the yield further. It also helps in attaining a better economy, reducing pollution as well as attaining better environmental sustainability. Reduction in cultivation time is another factor that plays a vital role in the selection of hydroponics as the best method of cultivation.

Identification of the most suitable hydroponic setup for different plant types is important for the proper growth of the plants. The identification has to be done based on the various advantages and disadvantages of each hydroponic method and the growth responses of the plants in different setups. Different hydroponic setups benefit various types of commercial or domestic ventures. For instance, small-scale hydroponic ventures are generally benefitted from the ebb and flow setup whereas a large-scale hydroponic setup is more beneficial using an NFT or wick system.

With a deep understanding of all five types of hydroponic setups, all of their pros and cons, and a comparative analysis of their performances in various scenarios, a comprehensive study in this regard can help the hydroponic farmers select the most appropriate hydroponic system according to the requirement. Factors like budget, technical skills, and requirements of the farmers also act as the most deciding factors in deciding the hydroponic setup to be selected.

7. RESEARCH DIRECTIONS

With the increased adoption and usage of hydroponics in the era of vertical farming, several future research directions concerning hydroponic vertical farming methods can be pursued. Hydroponics is a type of vertical farming method that consumes energy at every stage. Optimization of energy consumption is a major aspect that can be worked upon in the future for better performance and environmental sustainability. A recommendation system can be developed to select suitable crops in vertical farming systems. This will help in reducing the failures in adapting the hydroponic cultivation system caused due to incorrect selection of plants. Hydroponics can also be integrated with vermiculture to ensure better nutrient cycling and resource utilization. Another important research direction of hydroponic vertical farming can be checking the feasibility and success of vertical hydroponics in extreme conditions like deserts or arctic regions. Vegetation is difficult in locations with extreme climatic conditions like deserts and polar regions. The feasibility of a hydroponic vertical farming system in such geographic locations can be of great help to society and mankind.

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