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Overview of Hydroponics towards High Quality Production of Vegetable Crops

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Now a days, people are becoming more concerned about their diet, health and lifestyle. Clean eating and nutrition rich food is the key towards healthy life. In order to avoid or minimize the effect of leftover residues of fertilizer on crops, adoption of hydroponic systems could be an excellent approach, which is to be practiced in controlled conditions. Numerous crops with no pest infestation and without any pathogenic disease can be grown with an efficient utilization of resources under hydroponics-based systems. Labor cost can be minimized as no intercultural operations like weeding, ploughing, tillage etc. need to be practiced. Hydroponic system is a high-grade access towards physically and economically safe and nutritious food. For the healthy production of green leafy and other vegetables hydroponics system is being adopted in many countries like Netherlands, Australia, France, England, Canada and USA clinching around 70-90 % savings on water.

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1. INTRODUCTION

Hydroponics is the methodology of growing countless crops devoid of soil and with the presence of water. The Greek meaning of the word hydroponics is “hydro” means water and “ponos” means labor and was firstly introduced by William Frederick Gericke in 1930 from the university of California and introduced in India in 1946 by an English man W.j. (William) Shalto Duglas. Numerous crops like tomato, lettuce, spinach, cucumber have been used to grow in hydroponics as a result their roots were in water and not in dirt and soil. This epitome of modification of medium is an extraordinary approach towards the rapid growing population and urbanisation and aids in facing the challenges occurred due to declined cultivation area. Introduction of this technique has been thoughtful in minimizing the extent of infections caused by soil borne diseases like damping off and root rot. This strategy is supportive in using the fertilisers and water more efficiently in order to produce better quality crops under controlled environmental (pH, moisture, temperature, light) and biological conditions (like pest attack). According to recent reports Europe is considered as the biggest market for producing quality crops grown hydroponically among which Spain, Netherlands and France are the three top producing countries followed by USA [1]. With the launch of this system, producers and growers have become aware of growing crops in more precise and environment friendly manner. Several varieties of crops can be grown throughout a year in hydroponic system as it is season independent and performs solely in controlled conditions [2]. This method gives relaxation to farmers and growers as several intercultural operations like weeding, ploughing, winnowing is not required and consequently saves time and energy. Regular examination and monitoring of crops is of critical importance to lessen the chances of any productivity loss caused due to microbial attack, Salinization or excess water. Nominal loss of nutrients has been observed in hydroponics as the nutrients get dissolved in water and the solution reaches up to the plant roots which carries water and mineral to various other parts of the plant [2]. Green leafy vegetables have given superior output in this technique as production chances are maximum and wastage is minimal, for example in Lettuce 99% leaves are valid which are grown hydroponically and the value of selling the leaves is 40% more expensive than those which are grown traditionally [2]. Nowadays, people are becoming more aware of their health and eating habits due to the risk of many types of diseases like cancer, cardiovascular diseases and neurological diseases [3], All the consumers worldwide are keen to adapt healthy lifestyle by having healthy and fresh vegetables with no toxic fertiliser or pesticide residue on it, that’s why the presence of health-promoting chemicals is now a crucial factor for fruit and vegetable growers [2]. Fresh fruits and vegetables are actually abundant sources of bioactive substances with considerable benefits. Several important factors, including genotype selection and environmental circumstances (Air pressure, light, humidity and temperature), might affect the health effects of these beneficial chemicals [2].

2. TYPES OF HYDROPONIC SYSTEM

All over the globe, hydroponic techniques come in a wide variety. major categories
(A) The nutrient film method.
(B) The dynamic root floating method.
(C) The use of water culture.

A. The Nutrient Film Method

- Among all the methods mentioned above, this one is most widely used. For the lining of channels polyethylene plastic is used, which is made up of wood and plastic.
- For the circulation of water canals are used. Plants are hung above the solution, their roots hanging into it.
- In order to collect water in tanks or to reuse the water, pipes are constructed slightly sloped. Roots of plants which are larger in size can be easily penetrate the water [4].

B. The Dynamic Root Floating Method

- This method is a combination of various hydroponic systems.
- This DRFT system was created by Taichung district agricultural station in 1986 in Taiwan [5].
- From one end the nutrient solution is subjected to pass through all the tubes before gathering and return to the tank.
- Unlike NFT, the water pump is allowed to on and off several times to change the depth of the water rather than a continuously flowing water like in NFT.

- A pump may operate continuously and a separate drainage system could be set up to control the depth. Under the concave panels there are some floating boards in order to provide nutritional solution to the additional roots, called as aero roots.

C. Water Culture Technique

- Unlike, NFT and DRFT systems, this technique holds the plants on top of the nutritional solution, and the roots are allowed to dip freely in the nutrient solution.
- When water is left to stand there, root aeration can become a significant issue. So, an air bubbler needs to be use to oxygenate the water. On the other hand, baffles at the end of each bed will helps in oxygenating the water as it returns to the reservoir.

3. MANAGEMENT OF HYDROPONIC SYSTEM

The majority of the plant nutrients utilised in hydroponics are inorganic and ionic forms, which are dissolved in water. Different chemical fusions are used to supply each of the 17 components necessary for plant growth. The most popular nutrient solution for hydroponic systems is Hoagland's solution [6].

Table 1 displays the ideal pH and EC (pH is defined as the negative logarithm of H+ concentration and EC is the Electrical Conductivity, a degree to which a certain material conducts electricity) values of various crops which are grown hydroponically. The ideal EC range for majority of crops is between 1.5 and 2.5 dS m-1. In hydroponics, electrical conductivity (EC) control is crucial to maximizing nutrient absorption and enhancing the health and production of plants [7]. At high EC levels, osmotic pressure can prevent the uptake of nutrients, while low EC levels can negatively impact crop quality and output. Hence, excellent EC control is a useful technique for raising crop output and general quality [7]. As an illustration, tomato output in a hydroponic system increased as the Electrical conductivity (EC) in the nutritional solution rose from 0 to 3 dS/m, then decreased from 3 to 5 dS m-1, which was ascribed to an increase in water stress [8]. At the b dS m-1 resulted in an increase in crop height, fruit number, and pepper fresh weight. The pH of

Table 1. Optimum range of EC and pH values for hydroponic crops [6]

Crops	EC (dS/m)	pH
African Violet	1.2 to 1.5	6.0 to 7.0
Asparagus	1.4 to 1.8	6.0 to 6.8
Broccoli	2.8 to 3.5	6.0 to 6.8
Banana	1.8 to 2.2	5.5 to 6.5
Basil	1.0 to 1.6	5.5 to 6.0
Beans	2.0 to 4.0	6.0
Courgette	1.8 to 2.4	6.0
Carnation	2.0 to 3.5	6.0
Celery	1.8 to 2.4	6.0
Cabbage	2.5 to 3.0	6.5 to 7.0
Cucumber	1.7 to 2.0	5.0 to 5.5
Egg plant	2.5 to 3.5	6.0
Ficus	1.6 to 2.4	5.5 to 6.0
Lettuce	1.2 to 1.8	6.0 to 7.0
Leek	1.4 to 1.8	6.5 to 7.0
Parsley	1.8 to 2.2	6.0 to 6.5
Pak Choi	1.5 to 2.0	7.0
Peppers	0.8 to 1.8	5.5 to 6.0
Rose	1.5 to 2.5	5.5 to 6.0
Sage	1.0 to 1.6	5.5 to 6.5
Spinach	1.8 to 2.3	6.0 to 7.0
Strawberry	1.8 to 2.2	6.0
Rhubarb	1.6 to 2.0	5.5 to 6.0
Tomato	2.0 to 4.0	6.0 to 6.5

a nutrition solution controls the availability of vital plant components. The pH range of the nutrient solution that is best for the growth of plants is 5.5 to 6.5 [9]. However, certain species may deviate from this range. Once the plant has grown, it will alter the composition of the nutrient solution by excreting either acidity or alkalinity to change the pH, depleting some nutrients more quickly than others, and withdrawing water from the solution. [Wang *et al.,* 2017]. An ideal solution pH ranges around 5.5 to 6.5 is considered to be best of all solutions maintained by a mixture of three acids sulphuric acid (H2SO4), hydrochloric acid (HCl), nitric acid (HNO_3) and phosphoric acid (H_3PO_4). A change in pH leads to nutrient imbalance, and ultimately results into toxicity or deficiency in then plants. Therefore, it becomes important to take all precautions while maintaining the pH, EC, and nutrient levels in hydroponic solution.

4. HYDROPONICALLY GROWN LEAFY VEGETABLES

4.1 Lettuce

After comparing hydroponic lettuce with conventional grown lettuce, it has been found that, the hydroponic lettuce bears short life span. It has to be harvested after 35-40 days. It can be grown effectively by using NFT hydroponic system. For the yield optimization of hydroponically grown lettuce, horizontal and vertical hydroponic system was tested with various nutrient solutions [10]. A research has been carried out and the results were found that the yield and yield components can be boosted or increased by growing lettuce in recirculating hydroponic systems with a spacing of 50 plants m-2. [11].

According to the experiments conducted, it has been found that the nitrate content and productivity both differs in soilless and soil culture, however certain characteristics like leaf area, dry weight, ascorbic acid content remains unaffected [12]. Another research found that the composition of nutrition solution has no effect on marketable yield, shoot biomass or leaf area index of lettuce cultivated in floating system [13].

4.2 Spinach

Besides lettuce, some other vegetables were also grown hydroponically. An experiment has been conducted by taking spinach as model crop. A study in 2017 has examined that the spinach grown in hydroponic, aquaponic and conventional system differs in yield by using perlite and sphagnum moss and the yield of aquaponically grown spinach was tend to be higher than the hydroponically grown spinach [14].

One experiment showed that salinity has detrimental effect on vegetative development, but spinach has the ability of resistance to saline water with 5ppt [15].

4.3 Tomato

Tomatoes can be grown through several hydroponics systems, but NFT and deep flow technique (DFT) are often used for producing tomatoes successfully. A NFT system with continuous nutrient recycling solutions leads to increase production, growth, and mineral makeup in contrast to NFT with prolonged nutrient solution recycle yield was decreased [16]. Tests of different tomatoes cultivar were conducted in both open and closed hydroponic systems, and it was found that the marketable output for closed system was more whereas in open system fruit cracking was observed as a result [17].

4.4 Cucurbits

Other than tomatoes, Experiments were also conducted on cucurbits such as cucumbers and cantaloupes to grow them hydroponically in a successful manner. For the optimization of salinity of cucumber, an experiment has been performed in various hydroponics, and the result was found that the NFT was the most ideal for the growth of cantaloupes [6].
Apart from the Vegetables, several cut flowers and fruits like strawberry are subjected to grow hydroponically.

5. GROWING MEDIA IN HYDROPONICS

5.1 Organic Growing Media

- Coco peat: to make coco peat, husk which is produced by coconut is used, which is a naturally present in the nature. It was once thought of as a waste product because it is a byproduct of coconut fiber. This substance is corky, non-fibrous, spongy, and formed from coconut husk.
- Rice hulls: The product which is extracted from rice mile is called rice hulls. Rice hulls

are very advanced at enhancing drainage despite of being fairly lightweight. Sawdust and rice hulls are almost identical in terms of particle size and are resistance to breakdown. However, in media supplemented with rice hulls, Nitrogen depletion is not a significant issue. The hulls of rice may be utilized if they're readily available. Despite being a naturally occurring plant material, they decompose very slowly, much like coco coir, which makes them appropriate as a hydroponics growing system. There are four various types of rice hulls: fresh, aged, composted and parboiled, and carbonized.

5.2 Inorganic Growing Media

- Perlite: it is a non-combustible inorganic growing media used in hydroponics, as it is moisture resistant and has low density. unlike soil the water doesn't get leach out as it have ultimate water holding capacity. this material is inorganic material is secure to use as it is ecofriendly and does not cause any distraction to environment.
- Vermiculite: it is a brownish golden color substance which is porous and can absorb water easily and can hold 3-4 times of water. This substance is highly preferable in hydroponics as it increases nutrient retention and has great absorption capacity. It is a neutral clay having low electrical conductivity and pH of 7-7.5.

6. WATER CONSERVATION IN HYDROPONICS

As water has become more scarce and valuable resource, so, it needs to be conserved for future generations. Hydroponics require less water as compared to conventional farming, The water which we provide to soil is lost through leaching and not able to reach to the roots properly, whereas in hydroponics plant roots are completely dissolved in the water and covered by a nutrient mixed in water, thereby, feeding the plant and keeps the roots hydrated. Table 2 shows the hydroponic system to traditional agriculture and determines the savings in irrigation water, fertilizer, and improvement in food and water output.

70% to 90% irrigation water may cut in NFT based hydroponics by recycling the runoff water. While consuming 85%-90% water, it is quite feasible to produce high-quality, high-value crops under regulated hydroponic than conventional soil-based farming.

Table 2. Percentage of water and fertilizer consumption, vegetables yield percentage and the percentage of water productivity for different hydroponic systems as compared with conventional farming system [18]

Parameters	Hydroponic system			
	Media soilless system		Nutrient solution system	
	Open	Closed	Open	Closed
% Fertilizer saving	55	80	68	85
% Water productivity	1000	1600	2000	3500
%Productivity increase	100	150	200	250
% Irrigation Water Saving	80	85	85	90

7. GLOBAL HYDROPONICS MARKET AND COMMERCIAL HYDROPONIC PRODUCTION

In developing cities like Noida, Bangalore, Delhi, Chandigarh people are now growing green leafy vegetables but they don't have ample of land and time, So, hydroponics serve as a great substitute to conventional farming. Although, an initial cost of setup is high but it serves as a boon to those who desires to grow vegetables and fruits in metro cities. Also, acts as decorative purpose for house balconies and lawns [5].

- Cost analysis of vegetable crops under hydroponics systems
  Hydroponics provides several benefits to people and has made growing of crops easy in metro cities but cost expenditure for various crops also needs to be determined.
- Cost of cultivation of hydroponically grown tomato in 1 acre of land (when land is owned)

8. CAPITAL COSTS

Assuming land is currently owned by the owner, the capital costs per acre required would include-

- Cost of land Rs 0 lakhs
- Cost of Green House Rs 19 lakhs
- Drip Irrigation Rs 5 Lakhs
- Soil preparation Rs 40,000

- Mulching sheet Rs 20,000
- Project consultancy Rs 6 lakhs
- Grand Total (Every 5 years) Rs 30.5 lakhs (approximately) Yearly cost Rs 6.1 lakhs [19]

So, the total yearly cost involved in cultivation of 1 acre of tomato hydroponically is = (capital costs + operational costs)

= (9 lakhs + 6.1 lakhs) = 15.1 lakhs.

List 1. Operational Cost (For 1 acre per year)

▪ Poly bags	▪ Rs 24,000
▪ Coco pear	▪ Rs 1,35,000
▪ Trellising thread and clips	▪ Rs 25,000
▪ Nutrients per cropping cycle	▪ Rs 1,00,000
▪ Organic Pesticides per cycle	▪ Rs 30,000
▪ Seeds	▪ Rs 1,44,000
▪ Salary for 2 Employees	▪ Rs 240,000
▪ Electricity	▪ Rs 60,000
Grand Total (per year)	**Rs 9.0 lakhs (approximately)**

9. REVENUES

List 2. Assuming tomato growth for 1 year per acre

▪ Number of Kgs yield per plant	▪ 5 Kg
▪ Number of plants per acre of land	▪ 12,000 plants
▪ Number of yields per year	▪ 2 yields
▪ Price per Kg sold in the market	▪ Rs 25 per kg
▪ Total calculation	▪ 5×12000×2×25
Grand Total (per year)	**Rs 30 lakhs (approximately)**

So, the equated profit is about (30 lakh-15.1 lakh) = 14.9 lakhs i.e., nearly 15 lakhs.
[19].

9.1 Hydroponics Vs Conventional Farming

Hydroponics serves many benefits as compared to traditional farming; these are:

1. Labor expenses will be minimized as this method is operated through pumps or even computers.
2. Water supply to plant will be more precise and balanced as most water in conventional farming quickly goes through the root layer, hydroponic plants typically need one-tenth as little water as plants produced on soil do .
3. With the help of this system, more number of plants can be grown in a very short span as it requires less space thereby, providing more crops. So, hydroponics system provides more yield when compared to conventional farming [4].

Table 3 provides the lists of vegetable produced in soilless cultivation. In many countries like Abu Dhabi, Arizona, Belgium, California, Denmark, Germany, the Netherlands, Iran, Italy, Japan various commercial hydroponics farms were established, in later 1960s and 1970s.

9.2 Hydroponics- A Boon to Nation

Besides, helpful in growing vegetables, hydroponics provides several benefits. Whether there is no adequate soil for agricultural production or where the soil is contaminated with certain diseases [Damping off, Root rot, Vascular Wilt] then also cultivation of certain crop is possible. Labour work in several cultural activities including farming, fumigating, watering, and other procedures is largely removed. Maximum production of crops can be attained, making the system economically viable in places with high land prices and densities. This technique of farming utilises adequate water and nutrients. As a result, there are very few chances of losing or washing off of important nutrients [19]. By opting this approach, soil-borne plant diseases can be effectively eliminated from the nature. Using this system (timely nutrient feeding, watering, and root environment and various greenhouse-type activities), a more thorough control of the environment is feasible [19]. It is very simple to change the light, temperature, humidity, and composition of the air. If utilised with considerable caution, water that contains a high concentration of soluble salts can be used. If careful consideration is paid to routine leaching of the growth media in order to avoid salt accumulations, an open hydroponics system can be employed if the soluble salt concentrations in the water supply are greater than 500 ppm. Crops cultivated hydroponically are simpler to harvest than crops grown using traditional methods [19]. Crops produced hydroponically are more pleasant and healthier to eat, which have sufficient nutrients in it. Plants grown in hydroponic systems will receive the

Table 3. Crops that can be grown soil-less

	Cops name	Botanical name
Vegetables	Potato	*Solanum tuberosum*
	Brinjal	*Solanum melongena*
	Chilli	*Capsicum annum*
	Beet	*Beta vulgaris*
	Bean	*Phaseolus vulgaris*
	Winged bean	*Phaseolus vulgaris*
	Cabbage	*Brassica oleracea var: Capitata*
	Capsicum	*Capsicum annum*
	Cucumber	*Cucumis sativus*
	Cauliflower	*Brassica oleracea*
	Melon	*Cucumis melo*
	Green Onion	*Allium cepa*
	Raddish	*Raphanus sativus*
	Tomato	*Solanum Lycopersicum*
Leafy vegetables	Spinach	*Spinacea oleracea*
	Lettuce	*Lactuca sativa*
	Celery	*Apium graveolens*
Condiments	Corriander leaves	*Corriandrum Sativum*
	Mint	*Mentha spicata*
	Parsley	*Petroselinum crispum*

Source: [20]

same ultra-violet radiation protection as plants which are grown indoors in a protected environment. This technique allows for the development of exceptionally strong roots, which protect the plants from pollutants, various illnesses, and pest infestation [19]. It has become possible through this technique to produce 'off-season' vegetables while market prices are at their greatest value, so that growers can earn more. It also possible with vertical hydroponic growing system through which we can manage the limited space given for use. Plants are cultivated nearby to the storage places, which results in reducing the need for transportation [19].

9.4 Hydroponics- A Bane to Nation

Hydroponics is not a boon in every aspect. The construction for implement used in hydroponics system is highly expensive per square foot, which our farmers cannot afford. Before starting to cultivate any vegetable crop hydroponically, having the appropriate training or knowledge is a crucial necessity for the growers [19]. Understanding the basics of nutrition and plant growth is crucial, whether this information is unknown then our crop can deteriorate due to less or extra nutrient supply. In a closed system, there is a possibility of imported nematodes and soil-borne diseases which can quickly spread to all beds on the same nutrient tank [19]. The majority of plant kinds currently in use that are adapted to regulated growth environments must have undergone extensive research and development. The grower must keep surveillance to the plants constantly, since they react to excellent or bad nutrition incredibly quickly. The growers must have knowledge how to control the climate inside the building where the crop is cultivated [19].

10. CONCLUSION

In past few years, Hydroponics served as a promising approach for growing several crops altogether. Hydroponics made it possible to grow numerous crops all round the year, with very low labour expense. Hydroponics is a great alternative for raising crops in the areas where there is limited soil or no soil. In India, it is expected that hydroponic industry will grow exponentially to great extent in the upcoming years [6]. With the supply of constant, adequate and proper nutrition hydroponics will lead to the growth of 50% more crops than the conventional ones [19]. The scope of hydroponics has increased in a very short period of time leading to the increase in research and experimental areas all over the world [19].

11. FUTURE SCOPE OF HYDROPONICS IN INDIA

Hydroponics system has become very common all over the world, due to its controlled conditions. Anyone can setup hydroponic system even in the metropolitan cities but it is becoming unpopular in several cities and few small towns or rural areas due to lack of knowledge and hands on trainings skills [19]. Also, the initial setup cost is high. The majority of farmers in villages are unaware of this advance technique. The crops that are produced by conventional farming consumes residues of pesticides and fertilizers which not only deteriorates human health but also the soil heath [19]. So, hydroponics is an appreciable approach towards the healthy living and to produce chemical free food.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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