www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2021; 10(6): 629-634
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www.thepharmajournal.com
Received: 12-04-2021
Accepted: 20-05-2021

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Hydroponics in vegetable crops: A review

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Abstract
In the present situation, India needs food security which entails that each and every people must have physical and economic access to safe and nutritious food to meet dietary needs. Scarcity of usable water for agriculture leads to production of lesser production of food which ultimately leads to hunger and malnutrition of a large number of people in our country. So, there is an utmost need for adoption of such technology in agriculture that can contribute towards water saving and have a positive impact on food production and availability. 'Hydroponics' is one such methodology of soilless cultivation and water use efficiency of this of this is much more than conventional system. Currently hydroponics cultivation is gaining popularity all over the world because of its management of resources in a very efficient way and production of quality foods. Several benefits of this technique include less growing time of crops than conventional crop growing in soil, round the year production, minimum disease and pest infestation and elimination of several intercultural operations like weeding, spraying, watering etc. which is labour intensive.

Keywords: Hydroponics, food security, water use efficiency, efficient resource management

Introduction
Hydroponics is a technique of growing plants in nutrient solutions (water containing fertilizers) with or without the use of an inert medium (sand, gravel, vermiculite, rock wool, perlite, peat moss, coir or sawdust) to provide mechanical support (Sharma *et al.*, 2018) [1]. Maharana and Koul (2011) [2] defined hydroponics as a technique of growing plants in soil-less condition with their roots immersed in nutrient solution. According to Savaas (2017), hydroponics can be briefly defined as cultivation of plants without soil. So, it is clear that in hydroponics plants are grown without soil and they get nutrients from nutrient solution added to water. The earliest published work on growing terrestrial plants without soil was found in the book 'Sylva Sylvarum' by Francis Bacon in the year 1627. The term 'hydroponics' is derived from two Greek words i.e. "Hydro" and "Ponos" means water and labour respectively. The first modern use of hydroponics was done by W.F. Gericke from the University of California during the 1930's. In India, Hydroponics was introduced in year 1946 by an English scientist, W.J. Shalto Duglas. He established a laboratory in Kalimpong area, West Bengal and had written a book on Hydroponics, named as 'Hydroponics- The Bengal System' (Pant *et al.*, 2018) [4]. Other similar terms related to hydroponic are 'aqua (water) culture', 'hydroculture', 'nutriculture', 'soilless culture', 'soilless agriculture', 'tank farming', or 'chemical culture'. A 'hydroponicist' is defined as one who practices hydroponics and 'hydroponicum' defined as a building or garden in which hydroponics is practiced (Jones, 2014) [5]. Most hydroponics systems operate automatically to control the amount of water, nutrients and photoperiod based on the requirements of different plants. (Resh, 2013) [6]. Various commercial and special crops can be grown using hydroponics including leafy vegetables, tomato, cucumber, pepper, strawberry and many more. Europe is considered the biggest market for hydroponics in which France, the Netherlands and Spain are the three top producers, followed by the United States of America and Asia-Pacific region (Prakash *et al.*, 2020) [7]. Due to the population explotion, urbanization and industrialization, the cultivable land area is declining day by day. The conventional methods of crop production are also facing several challenges due to abnormal climatic behaviours. So that, new and modern methods for growing sufficient food have to be evolved in order to feed the world's growing population sustainably. Change in growing medium can be an alternative approach for sustainable crop production and conservation of quick depleting land and available water resources. That's why this 'hydroponics' systems is becoming increasingly widespread over the world and according to the most recent report, it is

expected to reach a world growth of 18.8% from 2017 to 2023, corresponding to a global hydroponic market USD 490.50 Million by 2023 (Jan *et al*., 2020) [8].

Advantages of hydroponics

- Crops can be grown where no suitable soil for crop cultivation exists or where the soil is contaminated with some diseases.
- Labour for different intercultural operations like tilling, cultivating, fumigating, watering and other practices are largely eliminated.
- Maximum yield can be obtained thus making the system economically feasible in high-density and expensive land areas.
- This method can efficiently use water and nutrients. Therefore, it can lead to a reduction in pollution of land and streams because there is minimum chance of loss of the valuable chemicals.
- Soil-borne plant diseases can be eradicated very efficiently by adopting this system.
- More complete control of the environment is possible by using the system (i.e. timely nutrient feeding, irrigation and root environment) and different greenhouse type operations, the light, temperature, humidity and composition of the air can be manipulated very easily.
- Water which is carrying high soluble salts can be used if done with extreme care. If the soluble salt concentrations in the water supply are over 500 ppm, an open system of hydroponics can be used if thorough care is given to frequent leaching of the growth media in order to reduce the salt accumulations.
- Hydroponically grown crops are easier to harvest than conventional cultivation practices.
- Hydroponically grown crops are more palatable and better for consumption.
- Plant grown in hydroponic system can be protected from UV radiations just like they are within a protected structure.
- Plants grown through this system develop a very good and vigorous root system and it makes the plant risk free from contaminants and different diseases and pest attack.
- Production of ‘off-season’ vegetable is possible when market prices are highest.
- With vertical hydroponic gardening, space management can also be done.
- Plants are grown locally hence carbon mileage can be reduced.

Soil-less growing media used in hydroponics

The growing media which is suitable for using in hydroponics system should have following characteristics-

a. It must act as a source of nutrient for proper plant growth and development.
b. It should have a very good water holding capacity.
c. It must supply water and gases to the plant simultaneously.
d. It must provide adequate support to the plant

Organic growing media

Coco peat

It is byproduct of coconut husk. Coconut peat is used for production of a wide range of soil-less crops like tomato, eggplant, cucumber, capsicum, etc. with no harmful environmental impact. The high water holding capacity of the coco peat provides a buffer in high temperatures and high crop load demand without compromising the air supply.

Rice hull

Rice hulls are a by-product of the rice milling industry. Although these are extremely light in weight, rice hulls are very effective in improving drainage. The particle size and resistance to decomposition of rice hulls and sawdust are more or less similar. However N depletion is not a serious problem in media amended with rice hulls. Depending on the availability, rice-hulls may be used. Even though they are an organic plant material, they break down very slowly like coco coir, making them suitable as a growing media for hydroponics. Rice hulls are referred to as either fresh, aged, composted and parboiled or carbonized. Fresh rice hulls should be avoided as a growing media of hydroponic system because there is high probability of presence of the contaminants such as rice, fungal spores, bacteria, decaying bugs and weed seeds. Parboiled rice hulls (PRH) are done by drying the rice hulls after the rice has been milled from them. This kills the spores of fungus, bacteria and any other microorganisms and thus helps in the production of a sterile and clean product.

Inorganic growing media

Perlite

It is grey white silicate material of volcanic origin, neutral in pH and expands from four to twenty times its original volume when it is quickly heated to a temperature of approximately 1600-1700º F. This expansion is due to the presence of two to six percent combined water in the crude perlite rock, which causes the perlite to pop in a manner similar to that of popcorn. The surface of each particle is covered with tiny cavities, which provide an extremely large surface area. These surfaces help in holding the moisture and nutrients and make them available to plant roots. In addition, because of the physical shape of each particle, air passages are formed which provide optimum aeration and drainage. Because perlite is sterile, it is free of diseases, seeds, and insects.

Sand

Sand is actually a very common growing media used in hydroponics. Sand is like rock, just smaller in size. As the particle size is smaller and finer than regular rock so there is no chance of quick drainage of moisture. Sand is also commonly mixed with Vermiculite, perlite or coco coir. It helps retaining moisture as well as helps in aerating the mix for the roots.

Vermiculite

Chemically, it is hydrated magnesium aluminium silicate. Vermiculite is a micacious mineral produced by heating to approximately 745ºC the expanded, plate-like particles, which are formed, have a very high water holding capacity and aid in aeration and drainage. Vermiculite has excellent exchange and buffering capacities as well as good ability to supply potassium and magnesium. Though vermiculite is considered as less durable than sand and perlite, its chemical and physical properties are very desirable for container media.

Rock wool

Rockwool is prepared by melting mixture of basalt, limestone at a temperature of 1600 ºC. The molten mass is then spun at a high speed into thin fibers of 0.005 mm diameter, treated with certain additives (a resin) to bind the fibers together and pressed into slabs of various sizes. Rockwool is also produced as a loose flock, which is used as a growing medium in pots, in a similar way as peat, or as an additive to other media.

Oasis cubes

Oasis cubes are looking similar to rock wool cubes and also have similar properties. But oasis cubes are more like the rigid green or white floral foam which is used by forests to hold the stems in their flower displays. Oasis cubes are open cell material which means that the cells can absorb both water and air. While oasis cubes are similar to rock-wool, Oasis cubes do not become waterlogged as easily as rockwool cubes.

Hydroponics structures and their classification

The techniques which are followed in hydroponics system include wick method, ebb and flow method, Deep water culture (DWC) method and drip method.

Wick method

This is simplest hydroponic system requiring no electricity, pump and aerators (Shrestha and Dunn, 2013) [9]. In this method, plants are placed in growing medium like coco coir, vermiculite, perlite with a nylon wick running from plant roots into a reservoir of nutrient solution. Water is supplied to plants through capillary action. This system is not applicable for heavy water requiring crops.

Ebb and flow method

This system works on the principle of flood and drain. In this system, the nutrient solution is pumped from a reservoir into the growing medium, flooding it with solution for a short period and then the nutrient solution is allowed to flow out of the rooting medium back into the reservoir. This outflow of nutrient solution from the growing medium draws air into the rooting bed, providing a source of O_2. From the moist rooting medium, plants are able to obtain water and nutrient elements. Again, in such a system of nutrient solution delivery, the roots experience a changing environment, which may not be ideal for best plant growth and development, although plant performance is usually satisfactory with this hydroponic technique (Jones, 2014) [5]. In this system, the problem of root rot, algae and mould is very common therefore, some modified system with filtration unit is required (Nielsen *et al*., 2006) [10].

Deep water culture method

In this method, plant roots are suspended in water rich in nutrients and air is supplied directly to the roots by an air stone. A classic example of such type of method is hydroponics bucket system. In this system, oxygen, nutrient concentrations, salinity and pH should be monitored regularly and very carefully as there is a chance of rapid growth of algae and moulds in the reservoir (Domingues *et al*., 2012) [11]. Vegetables like cucumber and tomato can be grown very successfully by adopting this method.

Drip method

Both home and commercial hydroponic cultivators widely use this method. Water or nutrient solution from the reservoir is provided to individual plant roots in appropriate proportion with the help of pump (Rouphael and Colla, 2005) [12]. Plants are usually placed in such type of growing medium which is moderately absorbent and that's why the nutrient solution drips slowly. Different types of vegetable crops can be grown by using this technique.

Apart from those above mentioned techniques there are some other methods which are broadly classified on the basis of circulation of water. These are mentioned and described briefly here under.

Circulating methods

NFT (Nutrient Film Technique)

This method was developed in mid1960's by English scientist Dr. Allen Cooper. Thin film of nutrient solution flows through channels continuously bathing bare roots. At lower end of the channels nutrient solution gets collected and flows back to the nutrient solution tank. Spinach could be grown year round using NFT in greenhouse if proper cultivars and appropriate solution temperature can be choosen. (Ikeda *et al*., 1995).

DFT (Deep flow technique)

In DFT nutrient solution flows 2-3cm deep through 10 cm diameter PVC pipes. Plastic pots contain planting materials and their bottom portion touches the nutrient solution that flows in the pipes. Potted plants are arranged in one plane or in zigzag shape.

Non circulating method

Root Dipping methods

In root dipping technique plants are grown in small pots filled with little growing medium. Lower 2-3cm of the pots submerged in nutrient solution. Some roots are dipped in the solution while others hanging in the air.

Capillary action technique

Nutrient solution reaches to inert medium by capillary action. The technique is suitable for ornamentals, flowers and indoor plants.

Nutrient solutions

Plants require 17 essential elements for vegetative and reproductive development. The first three are carbon, hydrogen and oxygen. Other 14 are-

- Macro nutrients which include nitrogen, phosphorus, potassium, calcium, magnesium and sulphur among which first three are classified as primary nutrients and rest three are considered as secondary nutrients.
- Microelements include iron, manganese, copper, zinc, boron, chlorine, molybdenum, nickel
- In hydroponics, nutrient control is very easy
- Nitrogen generally helps in vegetative growth of plant.
- Phosphorus and potassium helps in flowering and reproductive growth of the plant.

System requirements

For successful cultivation of vegetable crops hydroponically, the following factors must be kept in mind.

- pH of solution should be in between 5.8-6.4 i.e. slightly acidic to neutral.
- Electrical conductivity of solution should be in the range of 1.2-3.5 Mho.
- Temperature of the total system should not exceed 65-78º F.

SWOT analysis of hydroponics system in India

Strengths, weaknesses, opportunities and threats (SWOT) analysis indicates a framework for helping the researchers or planners to identify and prioritize the business goals and to further identify the strategies of achieving them (Ommani, 2011) [14]. India is having huge opportunity to adopt hydroponics in a large scale in the future because India is having rich diversity in climatic condition which helps the hydroponics cultivars to grow varieties of crops and to market their product. Apart from this, low labour and input costs in India makes it an ideal destination for food outsourcing.

Strengths

- Hydroponics makes any land with water source useful for vegetable production.
- High yields can be obtained from lesser spaces.
- Due to the premium quality, produce can fetch premium prices.
- Less number of labour is required which means it is a less costly venture.
- Integrated pest and disease management can be done in a very effective way.

Weaknesses

- Till date, there is no association/ tie up with any industries regarding selling of the products or formation of any bodies among hydroponics cultivators.
- High initial cost of investment and capital expenditure (capex).
- It needs more diligence and devotion than conventional farming.
- There are no dedicated standards and laws in India till date.

Opportunities

- Branding, packaging and selling of the hydroponically grown produce can be done in a clean, healthy and unique way.
- More cash crops such as gingers, saffron, turmeric etc. should be tried to grow hydroponically.
- These crops are gaining good traction in India.
- Hydroponically grown crops can be sold to niche/ urban markets which fetches high return.

Threats

- There must not be any competition regarding price but on quality in between conventionally and hydroponically grown products.
- There is a wrong perception among some people that hydroponics is unnatural.
- Certain soil grown produce are being marketed vigorously and may be a threat to hydroponic produce as for eg. Calyx-On tomato.
- Inconsistent supply arrangement may also ruin the market intake.

Table 1: Vegetable crops suitable for hydroponics system

Leafy vegetables	Lettuce, Parsley, Leafy type chinese cabbage/ Pakchoi etc.
Other than leafy vegetables	Tomato, Chilli, Brinjal, Green bean, Beet, Winged bean, Sweet pepper, Cabbage, Cauliflower, Cucumbers, Melons, Radish, Onion etc.

Table 2: Vegetable production under hydroponics in India (Frezza *et al*., 2005) [15].

Vegetables	Production (g/ sqm/ day)
Carrot	56.5
Cucumber	226
Garlic	57
Ginger	57
Leek	57
Green bean	113
Lettuce	226
Onion	56.5
Pea	113
Potato	56.5
Salad greens	226
Tomato	113

Table 3: Expences and income for producing hydroponic vegetables/ sq m area (UNDP, 1996) [16].

Cost (US$)	Celery	Pepper	Lettuce	Cucumber	Radish	Tomato
Total cost/ m^2	2.31	2.87	1.67	2.12	1.82	2.84
Net Income/ m^2	28.55	14.25	40.26	5.28	33.03	25.15

Table 4: Yield of tomato under hydroponics and field conditions

Parameter	Hydroponics	Field conditions
No. of fruits/ plant	64	38
Yield/ plant (kg)	2.05	1.2
Yield (q/ha)	820	480
Days to fruit ripening	58	62

Table 5: Comparison between hydroponically and conventionally grown lettuce (Barbosa *et al*., 2016) [17].

Parameter	Hydroponics	Conventional
Yield (Kg/ m.sq/ y)	41	3.9
Water use (l/ kg/ y)	20	250

Table 6: Yield comparison of some vegetables between soil and hydroponic system (Lateef *et al*., 2018) [18].

Crop	Soil (avg per acre)	Hydroponics (avg per acre)
Lettuce	9-10 tons	300-400 tons
Strawberries	20-25 tons	50 tons
Cucumber	15-20 tons	200 tons
Tomato	10-12 tons	180-200 tons
Bell pepper	10-12 tons	120-140 tons
Potato	8-10 tons	60-70 tons
Cabbage	6-7 tons	10-12 tons

Cost of cultivation of hydroponically grown tomato in 1 acre of land (when land is owned)

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 yrs) Rs 30.5 lakhs (approx)

Yearly cost Rs 6.1 lakhs

Operational cost

The operational costs of a hydroponic farm growing tomato for 1 acre per year would include

▪ 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 (approx)

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.

Revenues

Assuming tomato growth for 1 year per acre assumptions include

▪ 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 (approx)

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

Disadvantages of hydroponics

- The cost of hydroponics unit construction per unit area is very high.
- Proper training or knowhow is an important prerequisite before starting up cultivation of any vegetable crop hydroponically. Knowledge of how plants grow and nutrition principle is very important.
- There is a chance of quick spreading of introduced soil-borne diseases and nematodes to all beds on the same nutrient tank of a closed system.
- Most available plant varieties adapted to the controlled growing conditions must require thorough research and development.
- The grower must observe the plants every day because the reaction of the plant to good or poor nutrition is unbelievably fast.
- The growers must have knowledge of climate control inside the structure.

Future scope of hydroponics in India

Presently in India, Hydroponic farming is as popular as it is on the moon. Most of the time, farms are owned by individuals hovering around or below the poverty line who work on the farm as well. Their lack of knowledge, lack of investment and lack of willingness to move out of their comfort zone all influence the unpopularity of hydroponics here. Most farmers are in rural areas and do not even know that something like hydroponics exists. Having said that, it can be stated that scope of hydroponics in future is very good in India because-

- The megacities in India are running out of drinking water. The major consumer of this water is agriculture. By moving from traditional agriculture to water-efficient technologies like hydroponics, one can bring in more than 80% savings in water usage which can then be used for drinking water supply.
- In India most of the vegetables we consume are with residual chemicals and that is very much harmful for our health. Along with this, unlike the developed world, the systems to track and monitor pesticide residue in food are not well developed in India. With growing health awareness, the consumers are looking for healthier produce and willing to pay a premium price for the same. Hydroponically grown crops can be a very potent source of chemical free food commodities.

Conclusion

Hydroponic culture is possibly the most intensive method of crop production in today's agriculture industry mainly used in developed and developing countries for food production in limited space. It is highly productive, conserves water, protective for environment and can be done in limited land and space. By providing constant and readily available nutrition, hydroponics allows to grow up to 50% faster than soil. It also provides higher yield than conventional method. The frame of hydroponics has increased dramatically in a short period of time leading to an increase in experimentation and research in area of indoor and outdoor hydroponic gardening.

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