Hydroponics as an advanced technique for vegetable production: An overview

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Hydroponics as an advanced technique for vegetable production: An overview

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ABSTRACT

Currently hydroponic cultivation is gaining popularity all over the world because of efficient resources management and quality food production. Soil based agriculture is now facing various challenges such as urbanization, natural disaster, climate change, indiscriminate use of chemicals and pesticides which is depleting the land fertility. In this article various hydroponic structures *viz*. wick, ebb and flow, drip, deep water culture and Nutrient Film Technique (NFT) system; their operations; benefits and limitations; performance of different crops like tomato, cucumber, pepper and leafy greens and water conservation by this technique have been discussed. Several benefits of this technique are less growing time of crops than conventional growing; round the year production; minimal disease and pest incidence and weeding, spraying, watering etc can be eliminated. Commercially NFT technique has been used throughout the world for successful production of leafy as well as other vegetables with 70 to 90% savings of water. Leading countries in hydroponic technology are Netherland, Australia, France, England, Israel, Canada and USA. For successful implementation of commercial hydroponic technology, it is important to develop low cost techniques which are easy to operate and maintain; requires less labour and lower overall setup and operational cost.

Key words: Nutrient Film Technique (NFT), water conservation, nutrient management, Hydroponic market

INTRODUCTION

Hydroponics is a technique of growing plants in nutrient solutions with or without the use of an inert medium such as gravel, vermiculite, rockwool, peat moss, saw dust, coir dust, coconut fibre, etc. to provide mechanical support. The term Hydroponics was derived from the Greek words *hydro'* means water and *ponos'* means labour and literally means water work. The word hydroponics was coined by Professor William Gericke in the early 1930s; describe the growing of plants with their roots suspended in water containing mineral nutrients. Researchers at Purdue University developed the nutriculture system in 1940. During 1960s and 70s, commercial hydroponics farms were developed in Arizona, Abu Dhabi, Belgium, California, Denmark, German, Holland, Iran, Italy, Japan, Russian Federation and other countries. Most hydroponic systems operate automatically to control the amount of water, nutrients and photoperiod based on the requirements of different plants (Resh, 2013).

Due to rapid urbanization and industrialization not only the cultivable land is decreasing but also conventional agricultural practices causing a wide range of negative impacts on the environment. To sustainably feed the world's growing population, methods for growing sufficient food have to evolve. Modification in growth medium is an alternative for sustainable production and to conserve fast depleting land and available water resources. In the present scenario, soil less cultivation might be commenced successfully and considered as alternative option for growing healthy food plants, crops or vegetables (Butler and Oebker, 2006). Agriculture without soil includes hydro agriculture (Hydroponics), aqua agriculture (Aquaponics) and aerobic agriculture (Aeroponics) as well as substrate culture. Among these hydroponics techniques is gaining popularity because of its efficient management of resources and food production. Various commercial and specialty crops can be grown using hydroponics including leafy vegetables, tomatoes, cucumbers, peppers, strawberries, and many more. This article covers different aspect of hydroponics, vegetables grown in hydroponics system and global hydroponic market.

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HYDROPONIC STRUCTURES AND THEIR OPERATION

Hydroponic system are customised and modified according to recycling and reuse of nutrient solution and supporting media. Commonly used systems are wick, drip, ebb-flow, deep water culture and nutrient film technique (NFT) which are described below (Fig. 1).

Wick System

This is simplest hydroponic system requiring no electricity, pump and aerators (Shrestha and Dunn, 2013). Plants are placed in an absorbent medium like coco coir, vermiculite, perlite with a nylon wick running from plant roots into a reservoir of nutrient solution. Water or nutrient solution supplied to plants through capillary action. This system works well for small plants, herbs and spice and doesn't work effectively that needs lot of water.

Ebb and Flow system

This is first commercial hydroponic system which works on the principle of flood and drain. Nutrient solution and water from reservoir flooded

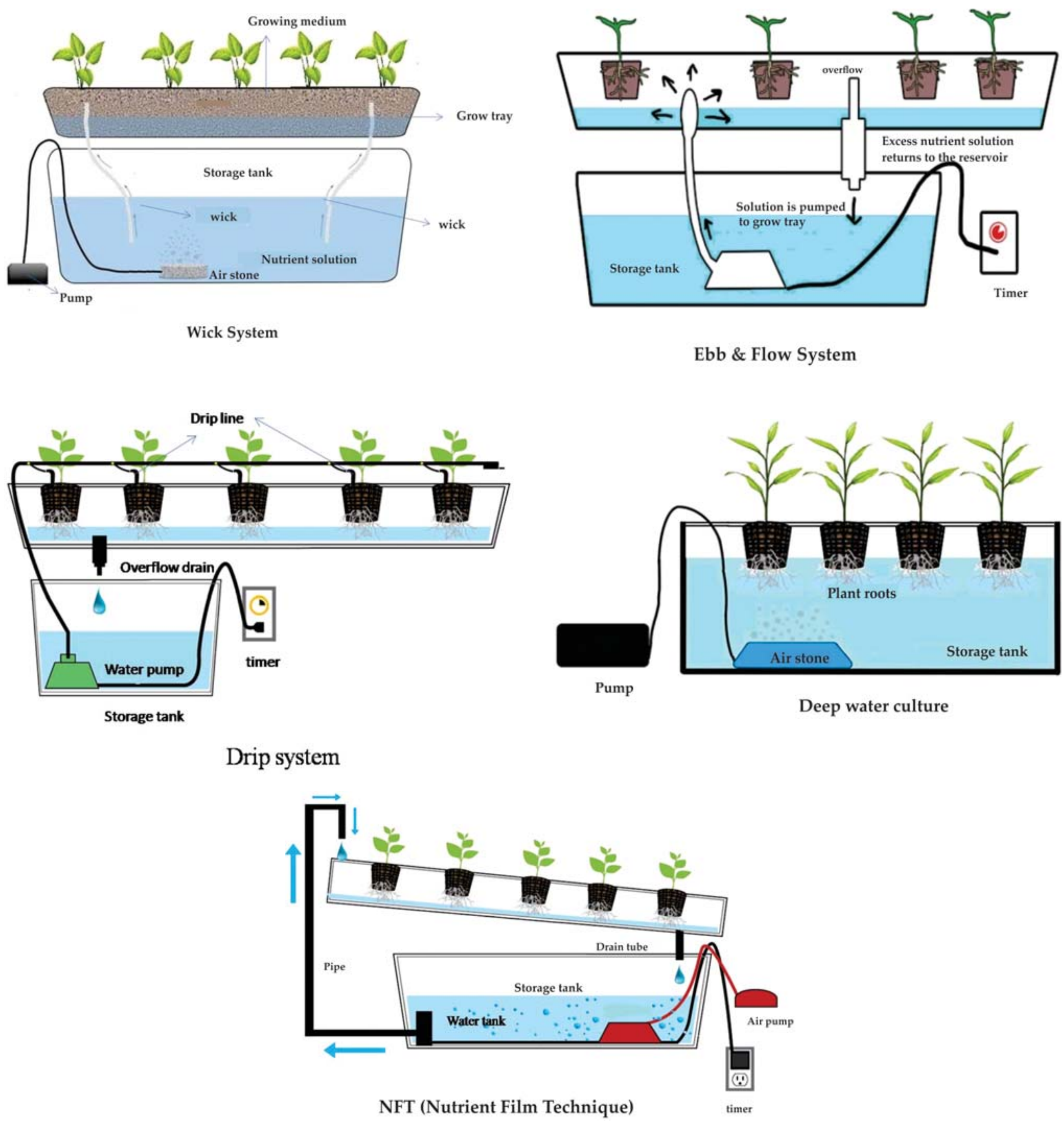

Fig. 1. Diagram of various structures of hydroponic system

through a water pump to grow bed until it reaches a certain level and stay there for certain period of time so that it provide nutrients and moisture to plants. Besides, it is possible to grow different kinds of crops but the problem of root rot, algae and mould is very common (Nielsen *et al.*, 2006) therefore, some modified system with filtration unit is required.

Drip system

The drip hydroponic system is widely used method among both home and commercial growers. 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). Plants are usually placed in moderately absorbent growing medium so that the nutrient solution drips slowly. Various crops can be grown systematically with more conservation of water.

Deep water culture system

In deep water culture, roots of plants are suspended in nutrient rich water and air is provided directly to the roots by an air stone. Hydroponics buckets system is classical example of this system. Plants are placed in net pots and roots are suspended in nutrient solution where they grow quickly in a large mass. It is mandatory to monitor the oxygen and nutrient concentrations, salinity and pH (Domingues *et al.*, 2012) as algae and moulds can grow rapidly in the reservoir. This system work well for larger plants that produce fruits especially cucumber and tomato, grow well in this system.

Nutrient Film Technique (NFT) system

NFT was developed in the mid 1960s in England by Dr. Alen Cooper to overcome the shortcomings of ebb and flow system. In this system, water or a nutrient solution circulates throughout the entire system; and enters the growth tray via a water pump without a time control (Domingues *et al.*, 2012). The system is slightly slanted so that nutrient solution runs through roots and down back into a reservoir. Plants are placed in channel or tube with roots dangling in a hydroponic solution. Although, roots are susceptible to fungal infection because they are constantly immersed in water or nutrient. In this system, many leafy green can easily be grown and commercially most widely used for lettuce production.

BENEFITS AND LIMITATIONS OF HYDROPONICS

Recently hydroponic technique is becoming popular because this is clean and relatively easy method and there is no chance of soil-borne disease, insect or pest infection to the crops thereby reducing or eliminating use of pesticides and their resulting toxicity. Besides, plants require less growing time as compared to crop grown in field and growth of plant is faster as there is no mechanical hindrance to the roots and the entire nutrient are readily available for plants. This technique is very useful for the area where environmental stress (cold, heat, dessert etc) is a major problem (Polycarpou *et al.*, 2005). Crops in hydroponic system are not influenced by climate change therefore, can be cultivated year-round and considered as off season (Manzocco *et al.*, 2011). Further, commercial hydroponic systems are automatically operated and expected to reduce labour and several traditional agricultural practices can be eliminated, such as weeding, spraying, watering and tilling (Jovicich *et al.*, 2003). Hydroponics saves large amount of water as irrigation and other kind of sprays is not needed and water logging never occurs. The problem of pest and disease can be controlled easily while weed is practically non-existent. Higher yields can be obtained since the number of plants per unit is higher compared to conventional agriculture.

Although soil-less cultivation is an advantageous technique but some limitations are significant. Technical knowledge and higher initial cost is fundamental requirement for commercial scale cultivation (Resh, 2013). Plant in a hydroponics system is sharing the exact same nutrient, and water borne diseases can easily spread from one plant to another (Ikeda *et al.*, 2002). Hot weather and limited oxygenation may limit production and can result in loss of crops. Maintenance of pH, EC and proper concentration of the nutrient solution is of prime importance. Finally, light and energy supply is required to run the system under protected structure.

pH AND ELECTRICAL CONDUCTIVITY (EC) MANAGEMENT

Plant nutrients used in hydroponics are dissolved in water and are mostly in inorganic and ionic forms. All 17 elements essential for plant growth are supplied using different chemical combinations. *Hoagland's* solution is used as most common nutrient solutions for hydroponic systems.

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

Crops	EC (dSm^{-1})	pH
Asparagus	1.4 to 1.8	6.0 to 6.8
African Violet	1.2 to 1.5	6.0 to 7.0
Basil	1.0 to 1.6	5.5 to 6.0
Bean	2.0 to 4.0	6.0
Banana	1.8 to 2.2	5.5 to 6.5
Broccoli	2.8 to 3.5	6.0 to 6.8
Cabbage	2.5 to 3.0	6.5 to 7.0
Celery	1.8 to 2.4	6.5
Carnation	2.0 to 3.5	6.0
Courgettes	1.8 to 2.4	6.0
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
Leek	1.4 to 1.8	6.5 to 7.0
Lettuce	1.2 to 1.8	6.0 to 7.0
Pak Choi	1.5 to 2.0	7.0
Peppers	0.8 to 1.8	5.5 to 6.0
Parsley	1.8 to 2.2	6.0 to 6.5
Rhubarb	1.6 to 2.0	5.5 to 6.0
Rose	1.5 to 2.5	5.5 to 6.0
Spinach	1.8 to 2.3	6.0 to 7.0
Strawberry	1.8 to 2.2	6.0
Sage	1.0 to 1.6	5.5 to 6.5
Tomato	2.0 to 4.0	6.0 to 6.5

Cooper's 1988 and *Imai's* 1987 nutrient solutions were also used for growing leafy vegetables, tomatoes and cucumber. Proper pH and EC of the nutrient solution is very essential and should be maintained properly for optimum plant performance.

Optimum range of EC and pH values for different hydroponic crops is shown in Table 1. Ideal EC range for hydroponics for most of the crops is between 1.5 and 2.5 dS m^{-1}. Higher EC will prevent nutrient absorption due to osmotic pressure and lower level severely affect plant health and yield. So, appropriate management of EC in hydroponics technique can give effective tool for improving vegetable yield and quality (Gruda, 2009). As an example, yield of tomato under hydroponic system increased as EC of nutrient solution increased from 0 to 3 dSm^{-1} and decreased as the EC increased from 3 to 5 dS m^{-1} due to increase of water stress (Zhang *et al.*, 2016). Level of EC @1.5, 2 and 3 dS m^{-1} at vegetative, middle vegetative and generative phase, respectively had increased crop height, fruit number and pepper fresh weight.

In a nutrient solution, pH determines the availability of essential plant elements. Optimum pH range of nutrient solution for development of plants is 5.5 to 6.5 (Trejo-Tellez and Gomez, 2012) for most species but some can differ from this range. Once the plants grows, it will change the composition of nutrient solution by depleting specific nutrients more rapidly than others, removing water from the solution and altering the pH by excretion of either acidity or alkalinity. Wang *et al.* (2017) found that mixture of three (HNO_3, H_3PO_4 and H_2SO_4) acids was much more effective than only single acid for maintaining an optimal solution pH of 5.5 to 6.5. Change in pH may cause nutrient imbalance and plant will show some deficiency or toxicity symptoms. Hence, care is required for maintaining optimum pH, EC and nutrient level in hydroponic solution. Crops such as vegetables, spices, flower and ornamentals, medicinal plants, fodders and up to some extent cereals can be raised through soil less hydroponic technique and is mentioned in Table 2.

PERFORMANCE OF VEGETABLES UNDER HYDROPONICS SYSTEM

A large number of plants and crops or vegetables can grow by hydroponics system. Quality of produce, taste and nutritive value of end products is generally higher than the natural soil based cultivation. Various experimental findings outlines that leafy greens (lettuce, spinach, parsley,

Table 2. Various species of plants grown under soil less hydroponic system

Type of crops	Name of the crops
Cereals	Rice, Maize
Fruits	Strawberry
Vegetables	Tomato, Chilli, Brinjal, Green bean, Beet, Winged bean, Bell pepper, Cucumbers, Melons, green Onion
Leafy vegetables	Lettuce, Spinach, Celery, Swiss chard, Atriplex
Condiments	Coriander leaves, Methi, Parsley, Mint, Sweet basil, Oregano
Flower / Ornamental crops	Marigold, Roses, Carnations, Chrysanthemum
Medicinal crops	Indian Aloe, Coleus
Fodder crops	Sorghum, Alfa alfa, Bermuda grass, Carpet grass

celery and atriplex etc) can be successfully and easily grown in hydroponic systems. Lettuce and spinach are most promising species to grow in integrated hydroponics and aquaculture systems because of its higher growth and nutrient uptake capacity.

Hydroponic research on lettuce, spinach and other leafy vegetables

Life cycle of hydroponic lettuce is very short compared to traditionally grown lettuce. Hydroponic lettuce can be harvested after 35 to 40 days of production. Lettuce can be successfully grown in NFT system and more than 8 crops per year can be grown efficiently in this system. Horizontal and vertical hydroponic system was also evaluated with different nutrient solutions for yield optimization of lettuce (Touliatos *et al.*, 2016). Growing of lettuce in recirculating hydroponic system at spacing of 50 plants m^{-2} significantly increased yield and yield components (Maboko and Plooy, 2009). Frezza *et al.* (2005) found that there is significant difference in productivity and nitrate content of lettuce in both soil less (floating system and substrate culture) and soil culture however, other traits like leaf area, dry weight and ascorbic acid content were remain unaffected. In non circulated and non-aerated system, air space between nutrient solution and tank cover also determines optimum lettuce yield. Another study observed that marketable yield, shoot biomass and leaf area index of lettuce grown in floating system was not affected by nutrient solution composition (Fallovo *et al.,* 2009). In other experiment, it was observed that both the hydroponic and organic system perform equal in terms of lettuce yield, quality and nitrate content, whereas, delayed harvesting not only increased yield but lower down nitrate level and reduced health hazards.

Besides lettuce, recently various hydroponic experiments were conducted using spinach as model crop. Ranawade *et al.* (2017) have compared spinach yield in hydroponic, aquaponics and in traditional system in which perlite (aquaponics) and sphagnum moss (hydroponics) were used to support the plants. The yield of the aquaponically cultivated spinach was slightly more than hydroponically cultivated spinach. The results of Mwazi *et al.* (2010) showed that salinity has negative impact on vegetative growth, but spinach has some tolerance to saline water with 5 ppt. When spinach grown in floating system, lack of aeration and hypoxia was not severe enough to influence yield and yield component as spinach is short duration crop but quality somehow was affected (Lenzi *et al.,* 2011).

Hydroponic swiss chard when grown in gravel film technique, plant density of 40 plant m^{-2} and 14 days of harvesting interval improved crop yield, leaf area, biomass and leaf fresh weight (Maboko and Plooy, 2013). Contrary to this, hydroponically grown swiss chard, lettuce and sweet basil contain high mineral content, high root/shoot ratio, low level of nitrates, than grown in soil culture, however, their nutrient uptake and yield was lower (Bulgari *et al.,* 2016). Effectiveness of rice husk biochar alone and in combination with perlite as substrates was also evaluated in NFT system for growing crops like cabbage, red lettuce, dill and mallow (Awad *et al.,* 2017).

Tomato and pepper grown under hydroponics system

Many hydroponic systems can be used for growing tomatoes but NFT and deep flow technique (DFT) are commonly used system for successful tomato production. Growing of tomato in NFT system with regular recycling of nutrient solutions improved growth, productivity and mineral composition whereas, in NFT with prolonged recycling of nutrient solution yield was reduced (Zekki *et al*., 1996). Open and closed hydroponic systems were evaluated for performance of various cultivars of tomato and in closed system higher marketable yield was obtained as because of fruit cracking, yield was reduced in open system (Maboko *et al*., 2011). Schmautz *et al.* (2016) compared yield, quality and overall tomato plant vitality in three different systems of hydroponics (NFT, drip system and floating raft) system. Researchers also investigate effects of plant population, pruning and plant growth regulators on yield and quality of hydroponically grown pepper in various systems. Effectiveness of different substrate (vermiculite + sand, Peat + perlite, rockwool) were evaluated on growth and yield of hydroponically grown green pepper and reported that peat + perlite had most significant effect on growing traits and yield of green pepper (Majdi *et al.,* 2012).

Besides tomato and pepper, cucurbits viz. cucumber, cantaloupes are successfully grown in various hydroponic systems. Experiments were conducted on cucumber for optimization of salinity level, EC and nutrients in various hydroponic. NFT system was found to be most suitable for growth and productivity of cantaloupe. Apart from

Table 3. 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 (AlShrouf, 2017)

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

vegetables, nowadays strawberry and different cut flowers are commercially grown under various hydroponic systems.

WATER CONSERVATION IN HYDROPONIC

As water becomes scarce and important as a resource, the use of hydroponics and other water saving technologies for crop production is needed now and is poised to popularize in time. Hydroponics uses substantially less water as compared to the soil farming. In soil farming, most of the water that we supply to the plants gets leached deep into the soil and is unavailable to the plants roots, whereas in hydroponics, plant roots are either submerged in water or a film of nutrients mixed in water is constantly encompassing the root zone, keeping it hydrated and nourished. Water is not wasted in this process, as it gets recovered, filtered, replenished and recycled. Waste nutrient solution can be used as an alternate water resource for crop cultivation under hydroponic system (Choi *et al.*, 2012). Savings in irrigation water, fertilizer and increase in vegetable and water productivity under hydroponic system as compared to conventional agriculture is depicted in Table 3. NFT based hydroponics can reduce irrigation water usage by 70% to 90% by recycling the run-off water. It is possible to effectively grow high value, good-quality vegetables under controlled hydroponic conditions using 85 to 90% less water than traditional soil based production. Water sources from groundwater or dam/river water commonly contain factors that can influence plant yield and affect plant condition, including salinity, dissolved solids and pathogens. While some of these factors can be beneficial to crops, others need to be minimised.

GLOBAL HYDROPONIC MARKET AND COMMERCIAL HYDROPONIC PRODUCTION

The Global Hydroponics Market has been estimated to cross USD 21203.5 million in 2016. By crop type, global hydroponics market includes tomato, cucurbits, lettuce & leafy vegetables, peppers and other food crops. Tomato forms the largest market segment and it accounts for 30.4% share of the global market, during 2018. Hydroponics crop production is expected to be more in tomatoes, lettuce and other leafy vegetables. As the consumers are becoming increasingly aware of the superiority of quality greenhouse-grown vegetables, the demand for hydroponics culture is rising in Europe and Asia-Pacific. Europe is traditionally the largest market that is implementing advanced techniques in hydroponics. Asia-Pacific forms the second largest market for hydroponics, which is expected to grow at a steady pace. Leading countries in hydroponic technology are Netherland, Australia, France, England, Israel, Canada and USA. Dutch are the world leader in commercial hydroponic having total area of 13000 ha under tomato, capsicum, cucumber and cut flowers (Netherlands Department of Environment, Food and Rural Affairs, NDEFRA) and this account 50% of the value of all fruits and vegetables produced in the country. Australian hydroponic production of vegetables, herbs and cut flowers of system valued about 300-400 million dollar which is approximately 20% of the total values of vegetables and cut flower production in Australia reported by Rural Industries Research and Development Corporation (RIRDC). Australia is the largest hydroponic lettuce producers in the world, and having strawberry cultivation is larger than USA and cut flower production is almost equal to USA. Canada and Spain are also expanding the area under commercial hydroponic system. Japan has started rice production by hydroponics technique to feed the people (De Kreij *et al.*, 1999). Israel grows large quantities of berries, citrus fruits and bananas in the dry and arid climate. Currently, demand of hydroponics cultivation has been increased in all the developing and developed countries (Trejo-Tellez and Gomez, 2012). In India, several tracts of wastelands having poor quality soil but plenty of water can be brought under hydroponics. Now a day's peoples in various big cities like Delhi, Chandigarh, Noida and Bangalore are growing some leafy greens and small herbs and spices on their roof tops and balconies for fresh consumption. The future for hydroponics appears more positive today than any time over the last 50 years. The startup costs to implement a hydroponic farm can vary widely but, they are usually higher than soil-based farming costs. Therefore, to foster the hydroponics industry's growth, it is important to implement technologies that reduce dependence on human labour and lower overall startup costs.

CONCLUSIONS

In recent years hydroponics is seen as a promising strategy for growing different crops. As it is possible to grow short duration crop like vegetables round the year in very limited spaces with low labour, so hydroponics can play a great contribution in areas with limitation of soil and water and for the poorer and landless people. In India, the hydroponic industry is expected to grow exponentially in near future. To encourage commercial hydroponic farm, it is important to develop low cost hydroponic technologies that reduce dependence on human labour and lower overall startup and operational costs.

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