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Review Article

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A review on hydroponic greenhouse cultivation for sustainable agriculture

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Abstract

The term 'Hydroponics' was derived from Greek word '*hydro'* means water and '*ponos'* mean labor. Hydroponics is a modern agriculture technique that uses nutrient solution rather than soil for crop production. Humans need water, food and living habitat to endure. As population increases the food demand also increases. The worry is that the existing system of agriculture will not be able to meet the food requirement near future as this system is facing many challenges. The objectives of this review paper are to discuss the hydroponic greenhouse technologies, impact of environmental factors on hydroponic greenhouse cultivation, advantages and challenges of hydroponic greenhouse system. This study revealed that hydroponic greenhouse cultivation is better option in the sense of utilization of inputs and improved crop production.

Keywords: Greenhouse cultivation, Hydroponics, Environmental factors

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Introduction

Humans need water, food and living habitat to endure. These things do not happen in interminable profusion and are resulting both from abiotic and biotic sources, making humans fundamentally hooked on the optimization of land area and the conservation of biodiversity. Within next 40 years human population is projected to increase from 7.0 billion to 9.5 billion people as human population increases. Food production will need to be doubled to compensate the parallel increase in demand for food species. The worry with this turn out to be plain upon the attention of the yield of existing structures of agriculture and fresh water harvesting: even with our energies, 1.0 billion people hurt from malnutrition modernly, and 1.2 billion live in zones with water shortage (Bellona Foundation, 2009).

Usually the most favorable or available medium for crop growth is soil. Soil provides the available the nutrients, air; water, etc. for effective crop growth (Ellis et al., 1974). Presence of micro-organism and nematodes instigating diseases, inappropriate soil response, poor drainage, soil compaction, soil degradation, etc. are the serious limitations of soil for effective crop growth (Beibel, 1960). The need for more land could be decreased by growing crops in towers. Increase in yield with efficient use of inputs (water, fertilizer, and pesticides) can be achieved through protected cultivation. The major advantage of hydroponic greenhouse cultivation is the efficient usage of natural light. Light play an important role in the development of fruit. In hydroponic greenhouse, light fall on both upper and lower part of the plant. Due to equal distribution of light, both upper and lower fruit develop at the same time (Despommier, 2009). Most profitable varieties of crops from cereal, green leafy vegetables, flower and fodder are growing well in the hydroponic systems (RIRDC, 2001). Resh and Howard (2012) studied the advantages of hydroponic systems like minimum use of pesticides, increase in yield, and water conservation. According to literature, many studies have been conducted on hydroponic leafy green, peppers, and tomato (Arias et al., 2000; Buchanan et al., 2013; Koyama et al., 2013).

Open field agriculture, will face some serious problems in near future like availability of land and agricultural productivity, deforestation, and soil erosion. In addition, some areas where, there is an issue of soil fertility, unfavorable topographical conditions, and soil is not available for cultivation of crop like urban areas, under such conditions soil-less culture or protected farming can be introduced successfully (Butler and Oebker, 2006). In the world, 115 countries have commercial greenhouse production (FAO, 2005). Total estimated area in the world for greenhouse crop production is 623302 hectares (Hickman, 2011).

Background

In 1627, the most primitive book on soil-less culture was *Sylva Sylvarum* published by Francis Bacon. In 1859-65, German botanists made developments in the techniques of soil-less culture. In 1929, solution culture was promoted by William Frederick Gerick for agricultural crop production. The word "Hydroponic" was firstly introduced by the William Frederick Gerick in 1937. In 1946, English scientist W.J. Shalto Duglas introduced the Hydroponics in West Bengal India. Nutrient film technique was developed by by English scientist Allen Cooper in 1960.

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In 1960-70, commercial hydroponics farms were developed in many countries of the world. Later, during 1980s many automatic and high-tech hydroponics farms were developed around the world (George, 2010).

Definition of Hydroponics

The term 'Hydroponics' was derived from Greek word '*hydro'* means water and '*ponos'* mean labor (Beibel, 1960). Hydroponics is a modern agriculture technique that uses nutrient solution rather than soil for crop production (Bridgewood, 2003; Hochmuth and Hochmuth, 2001a).

Hydroponic Techniques

Many studies have been conducted on hydroponic techniques. Generally, there are two techniques of hydroponics, named as solution culture method and media culture method. Comparison between both techniques are shown in table below regarding percentage of irrigation water saving, percentage of efficient fertilizer usage, increase in the percentage of productivity, and percentage of water productivity (Van et al., 1991; Van, 1995; Bohme, 1996; Gul et al., 1999; Dhakal et al., 2005; Tuzel et al., 1999; Van, 1999) (Table 1).

Table 1. Comparison between Hydroponic Techniques.

Parameters	Hydroponic Technique	
	Solution Culture	
	Open	Closed
Percentage of irrigation water saving	85	90
Percentage of fertilizer saving	68	85
Percentage of productivity increase	200	300
Percentage of water productivity	2000	3500

Solution Culture Method

It is also known as liquid hydroponics method. In this method plants are grown in solution culture and their roots are suspended directly in nutrient solution (Maharana and Koul, 2011). It can be further categorized into different subsections as below.

Continuous Flow Solution Culture

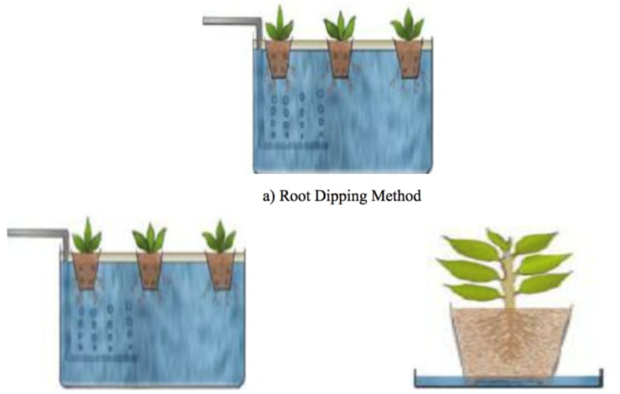
In this system pump is used to circulate the nutrient solution in plant roots and excess solution is collected and reused. Various studies have been conducted on continuous flow solution culture in different countries. This culture has two types of system named as nutrient film technique and deep flow technique shown in Figure 1. In nutrient film technique, the nutrient solution is pumped through the growing tube and flow over the roots of plants, then drain back into the reservoir. In deep flow system, PVC pipes with 10 cm diameter are used. 2-3 cm deep nutrient solution flows through the PVC pipes. PVC pipes have pots and plants are fitted in pots. The bottom of pots is in touch with the nutrient solution and pots contain planting materials. Plants are grown in pots (Maharana and Koul, 2011) (Figure 1).

a) Nutrient Film Technique b) Deep Flow Technique

Figure 1. Continuous Flow Solution Culture.

Static Solution Culture

In this system, nutrient solution is not circulated but provided only once when EC changes. It has three types of systems named as root dipping method, floating method, and capillary action method. In root dipping method, plants are grown in pots that have the growing media. The 2-3 cm bottom of pots is submerged into nutrient solution. Roots of plant are dipped in nutrient solution in this system and some are hanged in air. In floating method, shallow container (10 cm deep) can be used to grow the plants. Container is filled with nutrient solution. Plants are grown in pots that fixed on Styrofoam sheet. This sheet is floated on the nutrient solution. In capillary action technique, seedling/seed are planted in pots of different sizes and shape which is filled with inert medium. Shallow container having nutrient solution is used in this technique and pots are placed in this shallow container. By the capillary action nutrient solution reaches the inert medium. Ornamental, flower and indoor plants can be sown by using this technique (Maharana and Koul, 2011) (Figure 2).



a) Root Dipping Method

b) Floating Method c) Capillary Action Technique

Figure 2. Static Solution Culture.

Aeroponic System

Aeroponics is a method of growing plants where they are anchored in holes in Styrofoam panels and their roots are suspended in air beneath the panel. The aeroponics culture is usually practiced in protected structures and is suitable for low leafy vegetables like lettuce, spinach, etc. (Research News, 2008) (Figure 3).

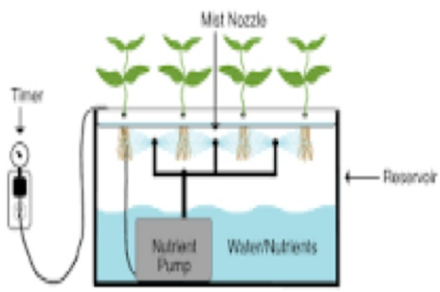


Figure 3. Aeroponic System.

Nutrients for Hydroponic Greenhouse Cultivation

Many studies have been conducted on crop nutrient requirement. Approximately, seventeen elements are required for proper plant growth. These elements are categorized into macro-nutrients and micro-nutrients (Table 3).

These elements are summarized in Table 3. Supply of nutrient solution to the hydroponic crops mainly depends on two parameters named as pH (Resh, 1993) and electrical conductivity (EC). The optimum range of pH of nutrient solution for hydroponic cultivation is 5.8 and 6.5 and good EC range is between 1.5 to 2.5 dS/m.

Crops For Hydroponic Greenhouse Cultivation

Crops need suitable environment for its successful growth. The only condition to achieve suitable environment for better crop production is the protected cultivation or hydroponic greenhouse cultivation. It is possible to grow cereals, vegetables, fruits, fodder, flowers, condiments, and medicinal plant in hydroponic greenhouses (Singh and Singh, 2012). The summary of those crops that are grown in hydroponic greenhouse are shown in Table 4. According to (Singh and Singh, 2012), hydroponic greenhouse yield per area is more than open agriculture yield per area. The yield comparison between hydroponic and open agriculture is shown in Table 5. This comparison showed that there is big difference between both types of method. This difference is due to controlled environment in case of hydroponic greenhouse cultivation and the re-use of nutrient solution.

Table 3. Summary of Nutrients for Hydroponic Crop Growth

Type of Nutrients	Name of Nutrients	Functions in Plants
Macro	Nitrogen	Chlorophyll, amino acids and proteins synthesis
	Phosphorus	Photosynthesis and growth
	Potassium	Enzyme activity
	Hydrogen	Water formation
	Oxygen	Release of energy from sugar
	Carbon	Formation of organic compounds
	Calcium	Cell growth
	Magnesium	Enzyme activation
	Sulfur	Formation of amino acids and proteins
Micro	Iron	Used in photosynthesis
	Boron	Vital for reproduction
	Chlorine	Help roots growth
	Copper	Enzyme activation
	Manganese	Component of chlorophyll
	Zinc	Component of enzymes
	Molybdenum	Nitrogen fixation
	Cobalt	Nitrogen fixation

Table 4. Summary of Crops for Hydroponic Greenhouse Cultivation (Singh and Singh, 2012).

Type of Crops	Name of Crops	
	Common Name	Botanical Name
Cereals	Rice	Oryza sativa
	Maize	Zea mays
	Wheat	Triticum aestivum
	Oat	Avena sativa
	Soybean	Glycin max
	Peas	Pisum sativum
Vegetables	Tomato	Lycopersicon lycopersicum
	Chilli	Capsicum frutescens
	Brinjal	Solanum melongena
	Green bean	Phaseolus vulgaris
	Bell pepper	Capsicum annum
	Beet	Beta vulgaris crassa
	Potato	Solanum tuberosum
	Cabbage	Brassica oleracea var.
	Cauliflower	Brassica oleracea
	Cucumber	Cucumis sativus
	Onion	Allium cepa
	Radish	Raphanus sativus
	Lettuce	Latuca sativa
Fruits	Strawberry	Fragaria ananassa
	Melons	Cucumis melo
Fodder crops	Sorghum	Sorghum bicolor
	Alfalfa	Cynodon dactylon
	Barley	Hordeum vulgare
	Bermuda grass	Cynodon dactylon
	Carpet grass	Axonopus compressus
Flower	Marigold	Tagetes patula
	Roses	Rosa berberifolia
	Carnations	Dianthus caryophyllus
	Chrysanthemum	Chrysanthemum indicum
Condiments	Parsley	Petroselinum crispum
	Mints	Mentha spicata
	Sweet basil	Ocimum basilicum
	Oregano	Origanum vulgare
Medicinal crops	Aloe	Aloe vera
	Coleus	Solenostemon scutellarioides

Table 5. Yield Comparisons between hydroponic and open field cultivation (Singh and Singh, 2012).

Type of Crops	Name of Crops	Hydroponic Yield (kg per ha)	Open Agriculture Yield (kg per ha)
Cereals	Rice	13,456.56	841.03-1,009.25
	Maize	8,971.0	1,682.07
	Wheat	5,606.9	672.83
	Oat	3,364.14	953.18
	Soybean	1,682.07	672.83
	Peas	15,699.32	2,242.76
Vegetables	Tomato	403,335.81	11,203.75-22,407.47
	French bean	47,097.96	-
	Beet	22,427.6	10,092.42
	Potato	156,852.29	17,925.98
	Cabbage	20,184.84	14,577.94
	Cauliflower	33,641.4	11,213.8-16,820.7
	Cucumber	31,398.64	7,849.66
	Lady's finger	21,306.22	5,606.9-8,971.04
	Lettuce	23,548.98	10,092.42

Impact of Environmental Factors on Hydroponic Greenhouse Cultivation

There are important environmental factors which effect the hydroponic greenhouse production e.g., light, temperature, air humidity, and CO_2 concentration. Usually, the level of these factors (too low or too high) adversely affects the hydroponic greenhouse production. The optimum level of temperature (Thompson et al., 1998; Tabatabaei et al., 2008; James et al., 1994; Kim et al., 2000; Kaya et al., 2000; Zornoza et al., 1987), relative humidity (Mathieu et al., 2006; CSUE, 2011; Jayaraman et al., 2011; Prosser et al., 2001; Seginer et al., 1991; Hikosaka et al., 2008), light intensity (Off-Grid-World, 2012; How Stuff Works, Inc., 2014; Simeonova et al., 2004; Chueca et al., 1984; Siddiqi et al., 2002; Nowak, 1980), and pH (Benoit and Ceustermans, 1988; Lieten, 1992; Sonneveld and Voogt, 1999; Jauert et al., 2002; Waisberg et al., 2004; Gibbs and Calo, 1959) for vine crops ranges from 20-24°C, 65-85 %, 100-130 Wm^{-2}, and 5.8-8.2 respectively.

Light Intensity

Several studies have been conducted on effect of low light or intensity on crop production. These studies have shown that low light is a problem in northern latitudes (Benoit, 1987; Grimstad, 1987; Gaudreau et al., 1994; Drews et al., 1995; Drews et al., 1996; Cockshull and Ho 1995; Dorais et al., 2001; Ottosen et al., 2003). The greenhouse structures reduced the amount of daylight received by 30 percent or more (Peet, 1999; Warren et al., 1992). When daylight is low or sub-optimal then greenhouse yield will be low because of the production of relatively small fruit (e.g., tomatoes), early in season (Grimstad, 1987; Cockshull and Ho 1995; Kays, 1999). Low light intensity reduced the leaf carbon assimilation, presumed by Pardossi et al. (2000). In flowers, accumulation of sugar decreased due to low light intensity. Additionally, sugar content and dry matter will be more if tomatoes and strawberries are grown in full sunlight and less in those which are grown in shade (Winsor, 1979; Weston and Barth, 1997; Caruso et al., 2004). According to Caruso et al. (2004), dry matter, sugar, acids, and taste determining compounds are reduced in case of shading effect in strawberry fruit (Caruso et al., 2004). In autumn-grown vegetables, taste is sometime poor due to shading effect of weather. Sign ensues, flavor quality of some crops affected by low light intensity (Winsor and Adams, 1976; Watson et al., 2002; White, 2002).

External and internal quality of vegetables crop is also affected due to excess lighting (Gaudreau et al., 1994; White, 2002; Hao and Papadopoulos, 1999; Dorais and Gosselin, 2002). In medicinal plant excess light increase the content of essential oils and other compounds (Hao and Papadopoulos, 1999; Dorais and Gosselin, 2002). Wide range of crops (tomatoes, bell peppers, eggplants, and pepinos) are adversely affected due to excess of light (Kays, 1999; Geissler, 1985). Cellular death, collapse of tissue, and degradation of the pigmentation are caused by excessive solar energy (Kays, 1999; Prohens et al., 2004).

Temperature

Chemical reaction and physical properties of plant are affected by the different level of temperature. Generally, growth rate of the different vegetable fruit increased with increasing air temperature (Marcelis, 1993; Dorais et al., 2004). According to Marcelis (1993), the biomass provision of the fruit increased with increasing temperature from 18°C to 25°C at the same plant (Marcelis, 1993). Organoleptic properties of vegetable are directly affected by low temperatures. Tomatoes having less juice and mealy taste is the clear indication of low temperature production (Anonymous, 1999; Bruckner et al., 2004). Quality of the most vegetable is affected by different temperature pattern. Marcelis and Baan Hofman-Eijer (1993) studied the effect of temperature fluctuations during crop production and compare the result with crop production at constant temperature. They found that sturdy fluctuation in temperature between day and night need to be avoided, because temperature fluctuation can decrease the quality of crop (Marcelis and Baan, 1993). Moreover, high temperature changes associated with growth factors can cause opening of cucumber (Geissler, 1985). Inspite of ventilation, shade, cooling, greenhouse temperatures arise in summer due to solar radiation. High temperature cause changes in the shape, color, and texture of tomato, cucumber and eggplant fruit (Geissler, 1985; Zipelevish et al., 2000).

Air Humidity

Water status and transpiration (water balance, transpiration cooling, and ion translocation) of hydroponic greenhouse plants is affected by air humidity (Bakker, 1984). Humidity is most difficult environmental factor to control and it is quite economical especially when heating. There are different methods to control the relative humidity. In cool weather, the utmost effective way to control relative humidity is to open the exhaust window slightly. Slightly open window escape heat allied with much of the water vapor. There are many other methods which have been tested but practical solutions have not been provided (Adams, 2002). When the vapor pressure deficits range 0.2 to 1.0 kPa then it has no effect on crop growth and development (Grange and Hand, 1987). Many studies have been done on effect of vapor pressure deficit and it is concluded that when vapor pressure deficit is low in hydroponic greenhouse then there is reduction in the average weight of tomato plant (Bakker, 1990a; Holder and Cockshull, 1990). When vapor pressure deficit increased from 1.0 to 2.5 kPa in hydroponic greenhouse then there is reduction in net accumulation of water in fruit (Guichard et al., 2001). Quality of vegetable is affected by high humidity levels; that cause increase in the diseases by spreading pathogens (Bakker, 1990b; Vonk and Welles 1995; Cockshull, 1998).

CO_2 Concentration

CO_2 concentration is one of the major environmental factors, several times throughout the history agronomy or horticulture the interest in CO_2 enrichment has risen and declined (Mortensen, 1987). Many studies have been done on effect of CO_2 enrichment and it is concluded that dry weight of plant, plant height, number of plant leaves, and lateral branches of plant increases with the increase in CO_2 enrichment in greenhouse (Mortensen, 1987). Moreover, other environmental factor (temperature and light) also increase with the elevated CO_2 concentrations (Mortensen, 1987). There should be a need of more research on CO_2 factor, how CO_2 enrichment affects the optimal levels of light, temperature and air humidity for a better product quality.

Challenges of Hydroponic Greenhouse Cultivation

High Initial Cost

Many studies have been done on the construction of hydroponic greenhouse structures. According to Tyson et al., (2004) the area of hydroponic structure should be able to sustain minimum 40 large plants (tomatoes, banana peppers, and bell-peppers) and minimum 72 small plants (spinach, lettuce, and strawberries). According to Hochmuth and Hochmuth (2001b), there should be an Arduino based climate control monitor system in hydroponic greenhouse to monitor the light intensity, temperature, carbon dioxide concentration, and humidity (Hochmuth and Hochmuth, 2001b). Many factors such as (availability of the system, the efficiency of the system, and transportation cost etc.,) should be kept in mind during installation of Arduino based climate control system and initial cost of this system also based on these factors (Taig, 2012). According to literature survey, the cost of Arduino based climate control system for commercial hydroponic greenhouse ranges from 500-2000 US Dollar (Grewal et al., 2011; Takakura, 2014).

High Maintenance and Running Cost

High maintenance and running cost is one of the major challenges for hydroponic greenhouse cultivation. Narrow and precise temperature range to attain the optimal plant growth is one of the major expenses for maintaining a hydroponic greenhouse (Wells, 2014; Tavassoli et al., 2010). Other expenses like resources to maintain the large concentration of nutrients in the water, energy for pumping the water-mixed nutrients, energy to run exhaust fans, and sensors etc., requires high maintenance and running cost.

High level of management is needed for hydroponic greenhouse. According to Shaw et al. (2001), high management skills are required for commercial production of any crop in hydroponic greenhouse system. The complexity of the system decides the level of management (Higashide et al., 2013). High level of management like production knowledge of different crop, technical skills, and adequate experience in hydroponic greenhouse field are the basic requirements for hydroponic greenhouses (He and Ma, 2010; Cantliffe and Vansickle, 2012). Grower must be committed to meet the entire requirement in an active means to make successful production (Sigrimis et al., 2013). Automatic system for regularly checking and regulating environment condition inside hydroponic greenhouse should be able to provide enough heating during winter season and chilling or shading during the summer season especially in a tropic area where there is extreme seasonal change (Kuennen et al., 2008).

Irrigation Management

Proper management about irrigation should be adopted and water should be free from contamination because there is more chance of diseases if water is contaminated (AI-Amri, 2007). High level of management and special training is required in area of agronomy (germination area for seedling, cultivar, and plant selection) (Othman et al., 2008; Succop and Newman, 2009). Crop selection plays an important role in initial and running cost of hydroponic greenhouse (Alexander and Parker, 2010). Crop production method (continuous flow and static flow) also requires high level of management skills (Stone, 2014). Supply nutrient to the crops is another area which requires high level of management (Peckenpaugh, 2004). Harvesting and storage requires high level of management with skilled labor (Savvas et al., 2007). Thus, modern type of agriculture systems needs high level of management for successful production (Vollebregt, and Brantford, 2014; Rathinasabapathi, 2011). Moreover, hydroponic greenhouse needs special and regular care (Carruthers, 2011).

Disease and Pest Management

Management related to pest and diseases are also a major problem for hydroponic greenhouse system. Detection of diseases in advance needs careful and high level of management because plant share same nutrient solution and this sharing can result in a quick spread of diseases (DeKorne, 2009). High degree of sanitation is the only solution for system to disease frees (Puri and Caplow, 2009; Jensen, 2007). When water mold is introduced into nutrient solution then most of diseases occur in plant and these water mold spread to all plant through circulating system (Silkova et al., 2011).

Advantages of Hydroponic Greenhouse Cultivation

No doubt hydroponic greenhouse system is facing many challenges, despite of all challenges this modern agricultural system is the most productive method for crop production. Hydroponic greenhouse system produced the higher nutritional value crop (Jones, 2012). Hydroponic greenhouse system has more benefits than disadvantages (Banda-Guzman and Lopez-Salazar, 2014).

In case of hydroponic greenhouse system percentage of land requirement, nutrient requirement, water requirement, and growing time is less (Banerjee and Adenaeuer, 2014). The estimated yield of vine crops is more in case of hydroponic greenhouse system (Mattas et al., 1997; Haifa Chemicals, 2014). Plants never come under stress in case of hydroponic greenhouse system because water and nutrient are always available to the plants (Ruth, 2009). The advantages of hydroponic greenhouse cultivation are summarized in Table 6.

Table 6. The summary of advantages of hydroponic greenhouse cultivation.

Sr. No	Advantages
1	Year-round crop grown
2	Crops are protected from extreme weather conditions
3	No or little use of pesticides
4	Water use efficiency is nearly about 90 %
5	Reduce the environmental pollution as no use of mechanical plow and other equipment's so that reduce the burning of fossil fuel
6	Human health friendly
7	Solar energy and wind energy can be used to generate electricity to controlling the hydroponic greenhouse environment
8	Sustainable urban growth
9	Reliable harvest
10	Crop can be grow in cities because soil is not required

Future of Hydroponic Greenhouse Cultivation

Hydroponic greenhouse system can play a vital role for the food production in the future (Butler and Oebker, 2006). The future of this technology is very bright because as world population increases, agricultural land come under colonies so to overcome such situation we will need unique system which produce food with limited inputs, hydroponic greenhouse system is only system which could meet the food requirement according to our needs. Rice is harvested four times annually in hydroponic technique, instead of single harvest in open field agriculture (Van et al., 2002). Hydroponic greenhouse system has an ability to feed millions of people in future in third world countries because water and crops are scarce/threaten in those regions although installation cost is high but in the long run all cost will decline, that will make this technology more feasible and convenient (Maharana and Koul, 2011; De Kreij et al., 1999; Raviv et al., 1998). This technology also has future in space and NASA had started working on this technology (Van et al., 2002). Because of its adaptation anywhere in the world it can be assumed that this technology has a bright future ahead.

Conclusion

The review on hydroponic greenhouse cultivation has been done in this paper. Ecological solutions to answer food requirements are today's extremely apprehension. In the developing countries, hydroponic greenhouse cultivation is rising quickly among other agricultural areas. It is concluded that hydroponic greenhouse cultivation technology can be utilized conveniently and it has the potential to raise the production and quality of crop tremendously year-round and has countless benefits. It may not result in any environmental pollution. The problem for need of more land can be solved by growing crops in towers. Increase in yield with efficient use of inputs (water, fertilizer, and pesticides) can be achieved in protected cultivation. The major advantage of hydroponic greenhouse cultivation is efficient usage of natural light. It can also be concluded that environmental factors have a huge impact on the quality of most of hydroponic greenhouse vegetables discussed above. Environmental factors not only affect the external and internal quality of the products, and physiological processes, but also lead to changes in appearance of products.

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