The Pharma Innovation Journal 2021; 10(1): 773-785

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2021; 10(1): 773-785

www.thepharmajournal.com
Received: 03-11-2020
Accepted: 09-12-2020

Soilless farming of vegetable crops: An overview

Dr. T Arumugam, G Sandeep and Dr. M Uma Maheswari

Dr. T Arumugam
Dean, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Periyakulam, Tamil Nadu, India

G Sandeep
Research Scholar, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Periyakulam, Tamil Nadu, India

Dr. M Uma Maheswari
Teaching Assistant, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Periyakulam, Tamil Nadu, India

Corresponding Author:
Dr. T Arumugam
Dean, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Periyakulam, Tamil Nadu, India

Abstract

Many challenges have come in recent years due to the booming world population. One of the major problems is the reduction of per capita land availability for soil-based farming. Due to these critical circumstances, it has become essential to develop advanced technologies and techniques to overcome the current scenario. Some of the latest technologies to overcome these problems are carried out of the soil and *in vitro* plant cultivation, few of these are mainly based on soilless crop farming. Soilless agriculture is the latest promising method to improve cultivation strategies to increase income. Other than the restoration of cultivable land, soilless farming with a closed circulation system has enormous advantages like recycling 85-90% of the water used for irrigation. Consequently, improved space and water management method showed better yield than traditional farming with promising results throughout the world. Based on above mentioned recent technologies soilless farming for sustainable and quality vegetable production is emerging as a recent technology for enhancing the productivity.

Keywords: Soilless culture, vegetable crops, hydroponics, nutrient solution

Introduction

Today world's 7.8 billion people use 1.5 billion hectares of land for food production and livestock. By 2050, the world population will be increased to 10.9 billion people as a result each of us requires a minimum of 1,600 calories per day. The civilization may expand to another 2.1 billion acres if cultivation continues to be practised as it is today. There simply is no such thing as so much fresh, arable earth. Agriculture often uses 70% of the world's fresh water available for irrigation making it unsuitable to drink due to pollution from fertilizer, pesticides, herbicides. If this trend continues, this population will be affected without drinking water. Due to various anthropogenic activities, various greenhouse gases are emitted into the atmosphere this increases temperature and groundwater level are drastically reduced making farmers difficult to feed extra 3 billion people by 2050. Due to these problems like limited space, water availability alternative means of cultivation need to be created by following vertical agriculture to solve the demerits of horizontal farming (Butler and Oebker, 1962) [14].

Soilless farming is a technique of growing plants in nutrient-rich solution with or without the use of an inert medium like sand, gravel, rock wool, peat moss, sawdust. Coconut fiber, vermiculite, perlite etc. to provide physical support to the plant. The term hydroponics was derived from the Greek word *Hydro* meaning Water and *ponos* meaning labour *i.e.* water work, which was coined by William Gericke, a professor in the early 1930s. He described that plants can be grown by suspending roots in water containing nutrients.

Hydroponics has been used efficiently to grow various crops such as lettuce, cucumber, tomato, herbs and other different types of flowers (Asao, 2012) [4]. It has its advantages over a conventional cultivating system such as rapid growth, high productivity, easy handling, efficient water usage (Barbosa *et al.*, 2015) [8] and lesser fertilizer usage (Rana *et al.*, 2011 and Cuba *et al.*, 2015) [19, 73]. In hydroponics, the nutrient concentration of the aqueous solution is controlled and monitored to observe the symptoms and nutrient deficiencies or toxicity in the plant system (Adrover *et al.*, 2013 and Cuba *et al.*, 2015) [1, 19]. Hydroponics has been very useful in toxicological studies in the accumulation of various contaminants in plants, to implement experimental studies in native and exotic crops for commercial or medicinal purposes and also in traditional crops like vegetables and ornamental plants.

In traditional cultivation, soil plays a major role in the cultivation of crops. Almost all the vegetables are directly or indirectly grown in open field soils. A well-drained pathogen-free field is the least expensive medium for plant cultivation, but the soil is not always a perfect package. Existing abiotic and biotic stress in soil affects agriculture and horticulture production. Besides this shrinking of land due to rapid urbanization and industrialization also affects agriculture production. To overcome these problems, better alternative to produce the crops using without any soil medium like hydroponics, aeroponics and aquaponics. This review article will be discussing the importance of soilless culture inefficient cultivation of vegetable crops, parameters affecting the soilless culture and management for successful commercial-scale production of vegetable crops via soilless culture. In this regard, it will be reviewed in these aspects in the following paragraphs.

History of hydroponics

Hydroponics has been used for thousands of years ago. This system has employed by many civilizations since many years ago. In Babylon, famous hanging gardens around 600 BC plants in the terrace were irrigated from Euphrates river was the earliest record of hydroponics. By 40 AD in ancient times, it is found that a man-made island city by the Aztecs in Tenochtitlan made plants float over the water where the roots are in direct contact with water (González Carmona and Torres Valladares, 2014) [29]. Currently, chinampas produce 40,000 ton/year of vegetables and flowers (Arano, 2007) [3] and it has been made an important agricultural heritage system (Aquastat, 1999) [2]. However, in the very early stages at 1627 a book was published on growing terrestrial plants without soil sylva sylvarum by Sir Francis Bacon, father of the scientific methods he named it as "*Water Culture*". In 1666, Robert Boyle, the Irish scientist explained his first experiment on plants grown with their roots in submerged water.

Similarly in 1699, John Woodward published his soilless culture in spearmint and found that plants performed less in impure water than distilled water. Mineral nutrition in solution for soilless culture was first performed by German botanist Julius Von Sachs and Wilhelm Knop in 1842 and 1895 respectively. A commercial water culture system was proposed by Professor William Frederick Gericke of the University of California. The term hydroponics was also coined by Gericke in 1937. Moreover, in 1940 he wrote the book named "Complete Guide to Soilless Gardening". Since 1938, Dennis R. Hoagland and Daniel I. Arnon were two plant nutritionists at the University of California developed a nutrition solution named "Hoagland Solution" which is successfully used till now commercially. In the year 1946, hydroponics was introduced in India by English Scientist W.J. Shalto Duglas who established a laboratory in Kalimpong, West Bengal. He also wrote a book named "Hydroponics the Bengal System".

Later around the 1960s and 1970s commercial hydroponics has been developed in Abu Dhabi, Arizona, Belgium, California, Denmark, German, Holland, Iran, Italy, Japan, Russian Federation and other countries (Sardare and Admane, 2013) [78]. Allen Cooper of England developed Nutrient Film Technique in the 1960s. 1980s many automated and computerized hydroponics kits have been developed and get popularized in the 1990s. Moreover, in recent times, various advanced extensive hydroponics research has been conducted by NASA for their controlled Ecological Life Support system (CELLS) to grow plants for the long term in space (Gruda 2009, Jensen 1997 and Savvas and Passam, 2002) [30, 37, 79]. In the year 2007, Arizona based farm produced 200 million pounds of tomato hydroponically (Javaid, 2020) [36]. As of now, Much AI-supported software has been developed by various private companies to monitor and control the hydroponic system through mobile phones using the internet or Bluetooth facility (Lakshmanan *et al.*, 2020) [45].

Types of circulating system in hydroponics

The hydroponic system has been majorly classified into two major groups they are

1. Open system
2. Closed system

Open system

In an open system of hydroponics, the nutrient solution which is in contact with the root system is used only once. It means that the nutrient solutions are not circulated or recycled. The major advantages of this system are that, there won't be a risk of infection in the plant system due to regular changes in the nutrient solution. (Jones, 2005) [38].

Closed system

In a Closed system, an entire nutrient solution used for the plant growth and applied for plant roots will be collected and returned periodically. That means this nutrient solution will be recycled regularly. In this system plants are grown in liquid medium or solid substrate like sawdust, rice husk, charcoal, sand, gravel, pumice etc. Water and nutrients are monitored while it gets recycled regularly. The major disadvantage of this system is that it depends on electricity (Lee and Lee, 2015) [46].

Some of the closed hydroponics systems are Deep Water Culture (DWC), Wick System, Ebb and Flow system, Nutrient Film Technique (NFT).

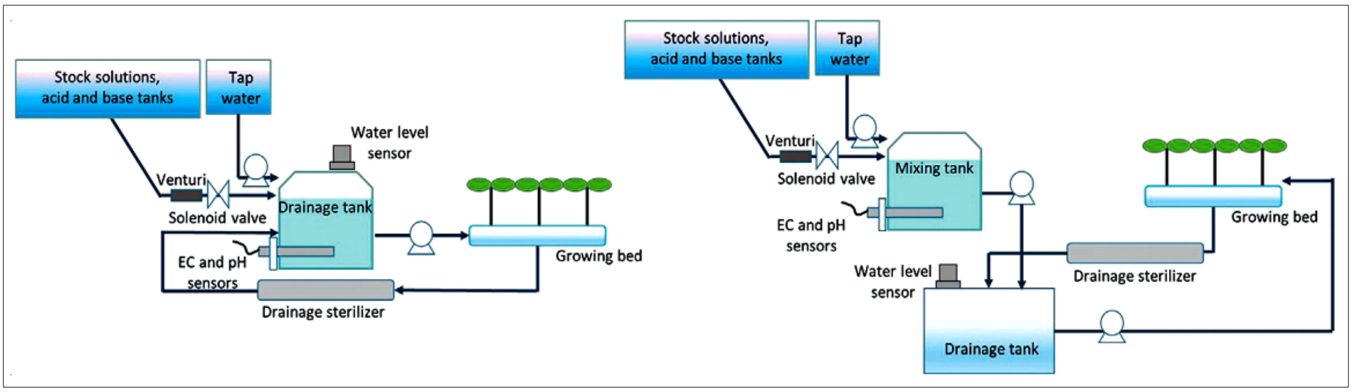

Fig 1: Schematic diagrams of closed (left) and open (right) hydroponic systems (Son *et al*., 2020) [82]

Types of hydroponics and soilless system

There are various types and different soilless system to grow plants, they are discussed below.

Hydroponics

Hydroponics is a simple system where plants are grown in water without using soil. It works on the principle that plants don't require soil for their growth instead they require vitamins, minerals, light, water, carbon dioxide, oxygen near the root zone. Hence hydroponics system requires inert growth media such as perlite or pumice where the nutrient-rich solutions are fed with macro and micronutrients that are necessary for their plant growth (El-Kazzaz and El-Kazzaz, 2017) [22].

Types of hydroponics systems

Wick or passive system

The wick system or passive system is a very less expensive technique where there is no recycling of nutrient solution instead the plant system absorbs solution by capillary action of the roots ad fibres that transport water to plants (Ferrarezi and Testezlaf, 2016) [24]. Wick system doesn't require electricity to transport nutrient solution so it is very useful in places where electricity is a big problem. As this system is very simple it can be efficiently used by teachers to educate children regarding basic idea on hydroponics in classrooms (El-Kazzaz and El-Kazzaz, 2017) [22]. This system is mainly used for small scale production and it is not recommended for the long-term cultivation of crops (Lee and Lee, 2015) [46].

Nutrient film technique (NFT)

Nutrient Film Technique is a closed system of hydroponic system where the nutrient solution is recycled and recirculated to provide a highly oxygenated nutrient solution to the roots of plants through a channel of PVC pipe arrangements. This system was developed by Allan cooper in the 1960s (Cooper, 1988) [18]. In this system, plant acquires the required nutrient and oxygen from the thin film of nutrient solution through their roots (Morgan, 2009) [58]. The nutrient solution is usually pumped from a holding tank to the sloping pipe where the roots are suspended and the run-off solutions are collected again in the holding tank, this cycle is repeated at regular intervals. Originally plants are grown on inert growth media placed in opaque containers. Recently, this NFT system has been modified with various supporting media and growing systems.

Deep water culture (DWC) or Deep flow technique (DFT)

Deep Water Culture is also known as Deep Flow Technique where the plants are cultivated on a floating or hanging support like rafts, panels, boards in a container containing a nutrient solution of about 10-20 cm (Van Os *et al.*, 2002) [94]. This system is a pioneer for many recent advanced versions of the hydroponics system. This system consists of a pump and aeration setup to grow plants roots (Hoagland and Arnon, 1950) [32]. The root of the plants is continuously made to get submerged in the nutrient solution with proper aeration. the oxygen concentration, conductivity, and pH have to be controlled to optimize the growth (Jones, 2005) [38].

Drip hydroponic system

The drip hydroponics system consists of two containers one on the top and the other on the bottom. In this setup, plants are placed on the top container and nutrient solutions are placed in the lower container. With the help of a pumping system, oxygenated nutrient solutions are pumped up to drips located near the root zone. After filtration, the used nutrient solution will be passed back to the nutrient tank. Oxygenation of water is achieved by placing aquarium stone in the nutrient solution (El-Kazzaz and El-Kazzaz, 2017) [22]. Plants with large root system can be grown under this drip hydroponics system.

Ebb and flow system

The Ebb and Flow system of hydroponics is very similar to the drip hydroponics system where there are two containers one at the top with plants and the other at the bottom with nutrient solution. In this system of hydroponics instead of pumping the nutrient through drippers, they are flooded to the plant roots. An overflow pipe is placed in the top container that determines the level of nutrient solution and also transfers the excess nutrient solution to the bottom container. Similarly, like that of drip hydroponics system plants with large root balls are grown in this system (Halveland, 2020) [31].

Aeroponics system

Aeroponics system classified under a closed system of soilless culture and it is the high tech type of hydroponics system. In this system, plants are supported by plastic or polystyrene panels and arranged horizontally at the top of the growing container. These panels are usually made of inert materials like plastic, steel coated with plastic film etc. to suspend the root system (Maucieri *et al.*, 2019) [55]. This system consists of three types of frameworks, the first framework is high pressure which doesn't generally use a water pump. The second framework is a low-pressure framework known as *soakaponics*. The water and nutrient solution is simply streaming out of the sprinkler i.e. mister heads (more water pressure) by using standard submersible water pumps. The third framework is ultrasonic foggers that make a mist (Burrage, 1998 and Domingues *et al.*, 2012) [13, 21].

The nutrient solutions are sprayed directly on the suspended roots with sprinklers through various types of nozzles at regular time intervals to avoid drying of the root zone. Misting of nutrient solution is achieved by different types of nozzles like Ultrasonic atomization foggers, High-Pressure atomization nozzle and Pressurized airless nozzles to mist the growing roots. Static pressure of about 60-90 Psi is maintained and controlled by a computerized system (Liu *et al.*, 2018) [49]. The spray duration will be around 30-60 seconds, this frequency depends on the type of crops, cultivation period, the growth stage of the plants and time. The Aeroponics technique is mainly suitable for small horticultural crops and has not been used popularly due to its high investment and management cost (Rakocy, 2012) [71].

Aquaponics system

Aquaponics is a type of soilless culture integrated with circulating aquaculture and hydroponics system followed for double harvest purpose of both fish and vegetable production in a symbiotic environment (Rakocy 2007) [70]. The Aquaponics system is equipped with a water pump used to pump out water from the fish tank to the plant growing container through a biofilter where nitrifying bacteria can grow and toxic compounds are broken down. Excess water in the growing container is recycled into Nutrients required for the plant growth will be provided from the fish grown water containing fish excreta which is rich in ammonia. The beneficial bacteria like *Nitrosomonas sp.* and *Nitrobacter sp.* convert ammonia to nitrites and nitrites are converted to nitrates through metabolic process respectively (Rakocy *et al.*, 2016) [72]. These nutrients are effectively absorbed by the plants for growth and development. Pinho *et al.*, (2017) [65] reported alternative effluent treatment through aquaponics to save water and maximize the utilization of nutrients from Bio-Floc Technology (BFT) of tilapia culture by cultivating three different lettuce varieties (Red lettuce, butter lettuce and crispy lettuce) along with Tilapia fish with better growth performance in butter lettuce and increase in fish weight.

This aquaponics system can ensure food security in urban area by cultivating vegetables where space is not sufficient and also where are scarcity of fertile land, soil degradation, lack of freshwater and problematic soil (Bindraban *et al.*, 2012 and Klinger and Naylor, 2012) [12, 42]. In recent days leading countries in aquaponics are India, Israel, China and Africa (Singh and Singh, 2012) [81]. Aquaculture can be effectively combined with three systems of hydroponics such as Deep-Water System, Nutrient Film Technique, flood and drain system, among these different systems DWC and NFT are the most widely used aquaponics system (Maharana and Koul, 2011) [50].

There are different types of fishes that can be widely cultivated along with plants and they are classified as air-breathing and water breathing fish. Some of the air-breathing fishes are Anabas, Pangasius and gourami. Water breathing fishes are Tilapia, Red-bellied natter, rohu, mrigal and catla. Even ornamental fishes can be grown in an aquaponics system and high yield can be obtained from both fish and plants (Azad *et al.*, 2016) [6].

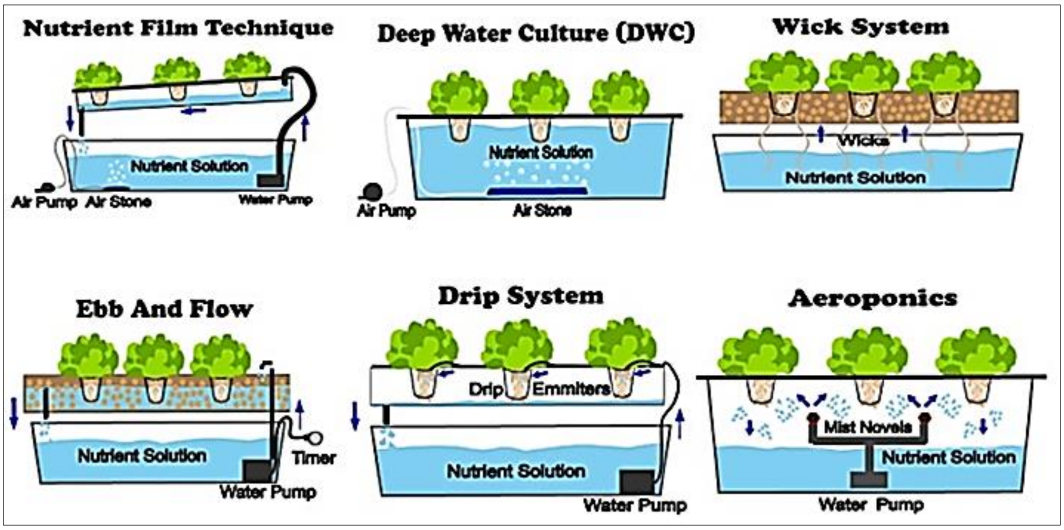

Fig 2: Types of aquaponics system

Table 1: Advantages of soilless culture over conventional farming (Jones Jr 2016 and Turner, 2008) [39]

Soilless farming	Conventional farming
Crops can be grown in all places like barren or contaminated land.	Crops cultivated in barren or contaminated lands are affected.
Vegetable crops grown are more resistant to salt stress.	Crops cultivated in saline soil are affected.
Biofortification of crops with nutrients can be achieved in soilless farming.	It is difficult and can be achieved by biotechnological approaches.
Pest and disease attack are less.	Pest and Disease attack is more.
Labour intensive works are not required.	Labour intensive is required.
Automated monitoring through computer system is possible.	It is not possible.
Water requirement is 1/10th of the conventional farming.	Water requirement is more.
Nutrient solution contains 25% of the required essential elements.	More wastage of applied Fertilizer in soil.
Less space is required for cultivation.	More space is required for cultivation.
Plant growth is faster and bigger.	Plant growth is affected by climate actors.
Yield per unit area is more.	Yield per unit area is less.

Suitable vegetable crops under soilless farming

The soilless farming system may help to produce different types of vegetable crops successfully, some of the vegetables cultivated under hydroponics system are (Table 2).

Table 2: List of crops that can be grown on commercial level using soil-less culture (Maharana and Koul, 2011) [50]

Type of crop	Name of the crops	Botanical name
Vegetables	Tomato	*Lycopersicon esculentum*
	Chilli	*Capsicum frutescens*
	Brinjal	*Solanum melongena*
	Green Bean	*Phaseolus vulgaris*
	Beet Root	*Beta vulgaris*
	Winged Bean	*Psophocarpus tetragonolobus*
	Bell pepper	*Capsicum annum*
	Cabbage	*Brassica oleracea var. capitata*
	Cauliflower	*Brassica oleracea var. botrytis*
	Cucumber	*Cucumis sativus*
	Melons	*Cucumis melo*

	Radish	*Raphanus sativus*
	Onion	*Allium cepa*
Leafy Vegetables	Lettuce	*Lactuca sativa*
	Kang Kong	*Ipomoea aquatica*
	Celery	*Apium graveolens*

Nutrient solution for the hydroponic system

The aqueous solution containing nutrients needed for plant growth and development along with air (oxygen) and water. Currently, 17 nutrient elements are considered for their essential growth are carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, copper, zinc, manganese, molybdenum, boron, chlorine and nickel (Salisbury and Ross, 1992) [77]. Elements like Carbon and Oxygen are obtained from the atmosphere (Trejo-Téllez and Gómez-Merino, 2012) [47]. The nutrient solution is prepared by dissolving inorganic salts in water, which dissipates as ions are absorbed by the plant root system (Table 3). The level of nutrients in the solution should be monitored regularly and the best time is between 6:00 and 8:00 am. The water and nutrient requirement varies every day based on the type of crop and age of the plant. This nutrient solution should be applied to the roots of the plant without wetting the foliage as it causes a scorching effect on leaves. Regularly around 20-50% of the nutrient solution in the hydroponic system has to be drained off and refilled with the new solution as it avoids the accumulation of toxic ions (Sardare and Admane, 2013) [78].

Table 3: List of commonly used fertilizers and acids in hydroponics (Trejo-Téllez and Gómez-Merino, 2012 and Jain *et al.*, 2019) [35, 47]

Fertilizers	Nutrient percentage	Solubility gL^{-1} at 20 °C
Calcium Nitrate ($Ca(NO_3)_2.5H_2O$)	N:15.5; Ca:19	1290
Potassium Nitrate (KNO_3)	N: 3; K:38	316
Magnesium Nitrate ($Mg(NO_3)2.6H_2O$)	N:11; Mg:9	760
Ammonium Nitrate (NH_4NO_3)	N:35	1920
Monopotassium Phosphate (KH_2PO_4)	P:23; K:28	226
Monoammonium Phosphate ($NH_4H_2PO_4$)	N:12; P:60	226
Potassium Sulphate (K_2SO_4)	K:45; S:18	365
Magnesium Sulphate ($MgSO_4.7H_2O$)	Mg:10; S:13	111
Ammonium Sulphate ($(NH_4)2SO_4$)	N:21; S:24	754
Potassium Chloride (KCl)	K:60; Cl:48	330

Mechanism of absorption

Among various mechanism involved in plant nutrition, the most important is absorption where the nutrients are absorbed in ionic form by hydrolysis of salts in the nutrient solution. Active roots play important role in the absorption of nutrients as anions and cations. Once these ions are entered into the plant system protons (H+) are expelled out to maintain the balance between electric charges (Haynes 1990). This maintenance in the ionic equilibrium cause changes in the pH of the solution. Absorption of the nutrient solution is affected by the climatic condition such as air, temperature and relative humidity, minor difference between air and substrate temperature cause better absorption and growth of the plants (Pregitzer and King (2005) [68], Masclaux-Daubresse *et al.*, 2010 [54], Marschner (2011) [53] and Manzocco *et al.*, 2011) [51].

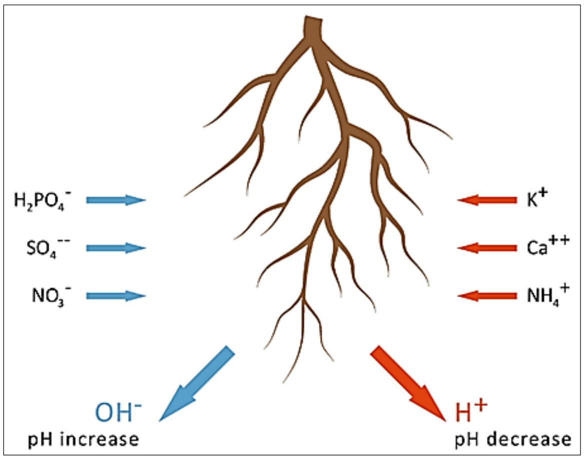

Fig 3: Mechanism of absorption

Commercially there are prefixed nutrient solutions used as nutrient solution in hydroponic system, that are used as prescribed and also modified based on the requirements (Table 4). There are various nutrients present in the nutrient solution they are as follows:

Nitrogen: Improves the production of leaves and growth of the stem. Highly mobile inside the plant system. Nitrogen Quantity higher than 10 mg/lit inhibits calcium and copper uptake.

Phosphorus: Stimulates root development. Important for flowers, fruits, leaves and stem growth. P on excess concentration reduce or block the absorption of K, Cu, Fe.

Potassium: Cell utilizes during assimilation of energy produced during photosynthesis and fundamental for cell division, protein synthesis, enzyme activation and acts a transporter. (Liu *et al.*, 2018) [49].

Calcium: Increases absorption capacity of potassium. Good availability of Ca in nutrient solution gives higher resistance to fungal and bacterial attack (Liu *et al.*, 2014) [48]. The deficiencies are displayed in different ways, e.g. apical rot in tomato and/or marginal browning of leaves in lettuce.

Magnesium: Important component in chlorophyll pigment. It is immobilized at a lesser pH value of 5.5 and competes with K and Ca.

Sulphur: plays a significant role in ameliorating the damages in photosynthetic apparatus caused by Fe-deficiency. It must be present in a 1:10 ratio with Nitrogen (McCutchan Jr *et al.*, 2003, Muneer *et al.*, 2014) [56, 59].

Iron: essential for chlorophyll production. Absorption is increased at pH 5.5-6.0.

Manganese: It forms as a part of many coenzymes and helps in the extension of root cells. Its availability is controlled by the pH of the nutrient solution and by competition with other nutrients.

Zinc: Essential component of the process of energy transfer in a plant. The absorption of zinc is strongly influenced by the pH and the P supply of the nutrient solution. pH should be between 5.5 and 6.5 to promote the absorption of Zn.

Boron: Essential for fruit and seed development. The pH of the nutrient solution must be below 6.0 and the optimal level is between 4.5 and 5.5.

Copper: Involves in respiratory and photosynthetic process. Its absorption is reduced at pH values higher than 6.5, whilst pH values lower than 5.5 may result in toxic effects (Rooney *et al.*, 2006) [75].

Molybdenum: It more essential for protein synthesis and nitrogen metabolism. Its better availability is at neutral pH (Gibson, 2007) [26].

Table 4: Commercially prefixed available nutrient solution and concentration ranges of essential mineral elements (Cooper 1988, Steiner 1966 and Baudoin *et al*., 1990) [10, 18, 84]

Nutrient	Hoagland & Arnon (1938)	Hewitt (1966)	Cooper (1979)	Steiner (1984)
N	210 mg L^{-1}	168 mg L^{-1}	200-236 mg L^{-1}	168 mg L^{-1}
P	31 mg L^{-1}	41 mg L^{-1}	60 mg L^{-1}	31 mg L^{-1}
K	234 mg L^{-1}	156 mg L^{-1}	300 mg L^{-1}	273 mg L^{-1}
Ca	160 mg L^{-1}	160 mg L^{-1}	170-185 mg L^{-1}	180 mg L^{-1}
Mg	34 mg L^{-1}	36 mg L^{-1}	50 mg L^{-1}	48 mg L^{-1}
S	64 mg L^{-1}	48 mg L^{-1}	68 mg L^{-1}	336 mg L^{-1}
Fe	2.5 mg L^{-1}	2.8 mg L^{-1}	12 mg L^{-1}	2-4 mg L^{-1}
Cu	0.02 mg L^{-1}	0.064 mg L^{-1}	0.1 mg L^{-1}	0.02 mg L^{-1}
Zn	0.05 mg L^{-1}	0.065 mg L^{-1}	0.1 mg L^{-1}	0.11 mg L^{-1}
Mn	0.5 mg L^{-1}	0.54 mg L^{-1}	2.0 mg L^{-1}	0.62 mg L^{-1}
B	0.5 mg L^{-1}	0.54 mg L^{-1}	0.3 mg L^{-1}	0.44 mg L^{-1}
Mo	0.01 mg L^{-1}	0.004 mg L^{-1}	0.2 mg L^{-1}	-

Sensors and controller systems

Root zone environment deciding factors like nutrient concentration, pH, dissolved oxygen, temperature and light affects the growth of the hydroponically grown plants. Real time measurement of these factors sensors are required. Electric current increases with increase in nutrient ion concentration, this could be measure using EC sensors. Water level sensors in nutrient solution tank loads the lacking water that are absorbed by plant through transpiration. Non-contact measurement of water level in the tanks can be achieved by placing ultrasonic or laser sensors. These sensors mainly function based on the principle of potentiometer where the solenoid valve triggers the pump system by changes in the electrical conductivity. Change in electrical conductivity activates the automated system with sensors to inject stock nutrient solution and water into the tank (Son *et al.*, 2020, Lakshmanan *et al.*, 2020) [45, 82].

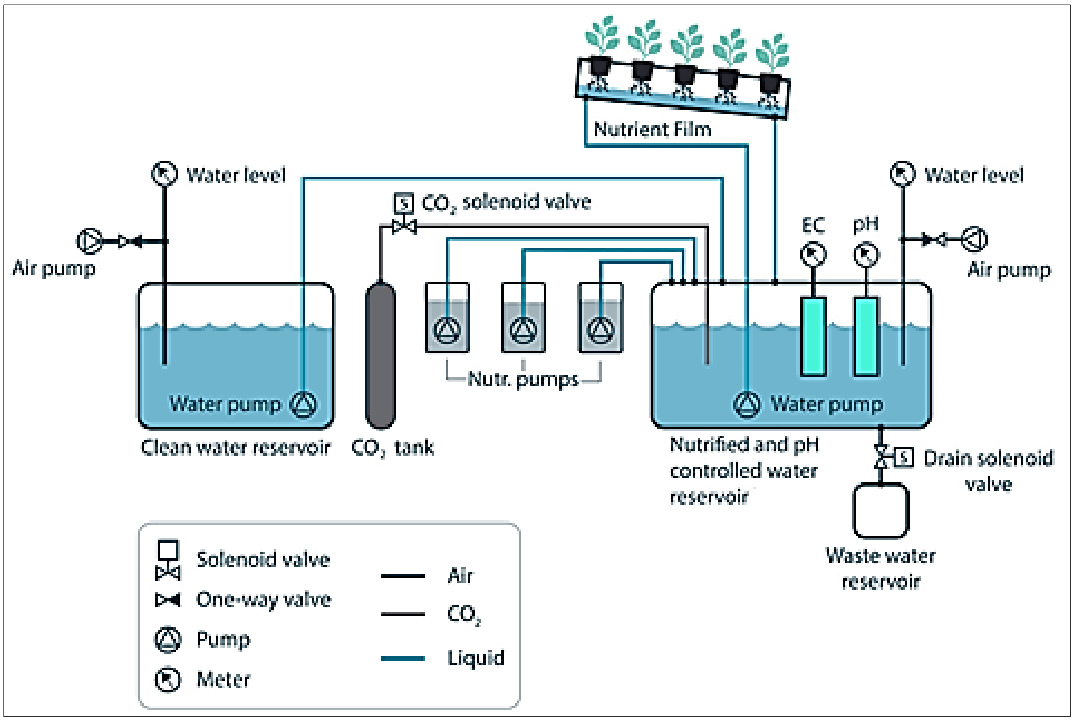

Fig 4: Automated smart hydroponics system structure (Sensorex)

Hydroponic system management and other factors affecting nutrient solution

The nutrient solution is the important medium to transfer nutrient to the plant system, these are affected by various factors like:

1. pH
2. EC
3. Temperature
4. Oxygenation
5. Light
6. Water quality and its disinfection

pH and Electrical conductivity (EC) of the nutrient solution

pH is the important parameter that determines the acidity or alkalinity of a solution. This indicates the relationship between the concentration of free ions H+ and OH- present in the nutrient solution, ranging between 0 and 14 (Ban *et al.*, 2020) [7]. pH value determines the nutrient availability for plants. Accordingly, pH adjustment must be done regularly due to the lower buffering capacity of the soilless system (Urrestarazu, 2004) [90]. Variables such as temperature, light, evaporation, processing of the tap water and the number of nutrients can also influence the pH level. *physiological alkalinity* is achieved When the anions are absorbed at a greater level than cations, for instance, nitrate, the plant excretes OH- or HCO3- anions to balance this electrical imbalance in charges inside the plant system (Marschner, 1995) [53]. The optimum pH range for soilless culture is between 5.8 and 6.5 (Sonneveld and Voogt, 2009) [83]. Hussain *et al.*, (2014) [33] reported that leafy vegetables, tomatoes and cucumber require proper pH and EC of the nutrient solution is very important for optimum growth.

The total ionic concentration determines the Electrical conductivity of the nutrient solution for better growth and development (Steiner 1961) [85]. The osmotic pressure of the nutrient solution is decided by the total amount of ions of dissolved salts which also decides the water potential (Taiz and Zeiger, 1998) [87]. Electrical conductivity is the indirect way to determine the Osmotic pressure of the nutrient solution i.e. total amount of salts in a solution. Hence this EC of the solution is a good indicator for better availability of nutrients. The ideal EC range for a hydroponic system is between 1.5 and 2.5 dSm^{-1}, it may vary from crop to crop (Table 5). When EC level increases absorption of nutrients is reduced due to a change in osmotic pressure (Çalişkan and Çalişkan, 2019) [15].

It is important to manage pH of the nutrient solution through chemical methods by addition of acids individually or combined such as nitric acid, sulphuric acid or phosphoric acid and EC can be managed by regular recycling of water (Trejo *et al*., 2012) [47].

Table 5: The optimum range of EC and pH values for vegetables grown in hydroponics crops (Sharma *et al.*, 2018) [80]

Crops	EC (dSm^{-1})	pH
Asparagus	1.4-1.8	6.0-6.8
Bean	2.0-4.0	6.0
Broccoli	2.8-3.5	6.0-6.8
Cabbage	2.5-3.0	6.5-7.0
Celery	1.8-2.4	6.5
Cucumber	1.7-2.0	5.0-5.5
Egg Plant	2.5-3.5	6.0
Leek	1.4-1.8	6.5-7.0
Lettuce	1.2-1.8	6.0-7.0
Pak Choi	1.5-2.0	7.0
Peppers	0.8-1.8	5.5-6.0
Parsley	1.8-2.2	6.0-6.5
Spinach	1.8-2.3	6.0-7.0
Tomato	2.0-4.0	6.0-6.5

Temperature control of the nutrient solution

The temperature of the nutrient solution has a direct relation to the quantity of oxygen consumed by the plants and inverse relation to the oxygen dissolved in it. Temperature also affects the solubility of the fertilizer and its absorption by the roots. Each plant species has a minimum and maximum optimum temperature level for its growth and it is maintained by implementing a heating and cooling system in the nutrient solution (Sago *et al.*, 2008) [76]. The optimum reported temperature solution for the nutrient solution is between 20-22ºC, if the temperature exceeds 23º-23.5 ºC plant root heath will be affected severely (Libia *et al.*, 2012) [47].

Oxygenation of nutrient solution

Oxygen consumption from the nutrient solution by the plant roots is increased by an increase in temperature (Table 6). During the respiration process, there will be an adequate increase in carbon dioxide in the root environment if the aeration is not adequate (Morard and Silvestre, 1996, Urrestarazu and Mazuela, 2005) [57, 91]. Oxygen requirement and consumption in the nutrient solution is based on the crop demand and photosynthetic activity increases. Decrease in dissolved oxygen below 3-4 mg/L inhibits the root growth and colour changes to brown, a preliminary symptom of lack of oxygen (Papadopoulos *et al.*, 1997 and Gislerød and Adams, 1983) [63, 27]. The supply of pure, pressurized oxygen gas into the nutrient solution to create an oxygen-enriched environment is called Oxy-fertigation (Chun and Takakura, 1994) [17]. This oxygen is generated commercially in hydroponic based farms by using potassium peroxide at the concentration of 1g/lit and in small scale farms, oxygen gas is made to dissolve into the nutrient solution by using aerators (Castaño *et al.*, 2010) [16]. Urrestarazu and Mazuela (2005) [91] found that the treatment with potassium peroxide increases the yield of sweet pepper and melon by 20 and 15% respectively, in comparison to the control, whereas there was no significant difference in cucumber yield.

Table 6: Solubility of oxygen at 760 mmHg of atmospheric pressure in water pure at various temperatures

Temperature (°C)	Oxygen solubility mgL^{-1} of pure water
10	11.29
15	10.08
20	9.09
25	8.26
30	7.56
35	6.95
40	6.41
45	5.93

Light requirement

Light is essential for the photosynthesis process to take place when the hydroponics systems are placed under protected condition. When desired sunlight is not acquired it majorly affects the plant growth in the hydroponics system. A minimum of 8-10 hours of light/day is required for the hydroponics system. Sunlight is ideal for hydroponic plants but when it is not available, Energy-saving LED lamps are efficiently used. For the Seedling and Vegetative stage, the plant requires blue spectrum with the less red spectrum and similarly for the Flowering stage, plants require Redder spectrum with a minimum of the Blue spectrum (Bayat *et al.*, 2018, Kim *et al.*, 2021) [11, 41].

Water quality and its disinfection

Water quality is the main element for the success of the soilless farming system. The quality of water will vary due to its different sources like rivers, rainwater, underground reservoirs or other treatments. These waters should be of high quality and free of pathogens for the success of farming without soil (Van Labeke *et al.*, 1994) [92]. Commonly reported diseases in the hydroponics system are fusarium wilt and verticillium wilt (Sutton *et al.*, 2000) [86].

One of the major disadvantages of the closed system of soilless farming is the rapid dispersal of soil-borne pathogens in the recirculating nutrient solution because once the disease spreads in the hydroponic system it is very difficult to control so it’s necessary to eliminate these pathogens there are various disinfection methods (Ohtani *et al.*, 2000) [61]. Diseases in hydroponics spread rapidly mainly due to change in microclimate in the hydroponic system (Göhler and Molitor 2002) [28]. There are different disinfection methods and some of them are:

Ozone treatment: Ozone is the second most powerful steriliser in the world and its function is to destroy bacteria, viruses and odours. An ozone supply of 10 g/h/m^3 water with an exposure time of 1 h is sufficient to kill all pathogens (Ohtani *et al.*, 2000) [61].

UV disinfection: Ultra-violet radiation (UV) is a proven process for disinfecting water, air or solid surfaces for eliminating bacteria and fungi an energy dose is recommended of 100 mJ/cm^2. For viruses, a dose of 250 mJ/cm^2 is recommended (Nosir, 2016) [60]. Zheng *et al.*, (2000) [96] stated that UV treatment of nutrient solution effectively removed *Pythium sp.* from tomato hydroponic system.

Heat treatment: When heat treatment is applied, a solution is heated for about 30 seconds to a temperature of 95 ˚C. At this temperature, all pathogens are killed (Runia, 1995). Heat treatment of nutrient solution found effective in hydroponics and aeroponics systems cultivating tomato and ginger respectively (Koohakan *et al.*, 2008) [43].

Slow sand filtration: For several years commercial growers have used a slow sand filtration installation to eliminate pathogens. A robust method to remove suspended solids from water (Kubiak *et al.*, 2015) [44].

Electrolysed water: It is utilized to split down the foul develop in hydroponic lines that frequently contains microorganisms, contagious spores and different organisms, this procedure is called Anodic Oxidation (AO) (El-Kazzaz and El-Kazzaz, 2017) [22].

Hydrogen peroxide: It is the less expensive method when compared to ozone, UV and filtration. It is the cheapest disinfection method of disinfecting water by treating with 400ppm of hydrogen peroxide and 0.3% of H_2O_2 reduces nematode infestation (El-Kazzaz and El-Kazzaz, 2017 & Barta and Henderson, 2000) [9, 22].

Membrane filtration: Membrane filtration can be classified into inverse osmosis (RO), hyper-, nano-, ultra- and micro-filtration based on the pore size of the membrane. Membrane filtration removes pathogens from the water without affecting nutrient concentration (El-Kazzaz and El-Kazzaz, 2017 & Van Os, 2008) [22, 93].

Chlorination: Chlorination is the most widely used sanitizing method of hydroponic system. Calcium hypochlorite ($CaO(Cl_2)$), normally known as ‘pool chlorine, is the most widely recognized disinfectant utilized by the producers (El-Kazzaz and El-Kazzaz, 2017) [22].

Growth medium

Growth medium is the substitute for soil in soilless culture systems. Solid medium provides physical support for the plant's root system by supplying oxygen, nutrients and water. The major function of the solid substrate is to supply nutrients and water to the plant without the risk of accumulating phytochemical chemical and toxic compounds (Patil *et al.*, 2020) [64]. Various growth substrates are available in the market and are commercially used they are classified as follows

Table 7: Classification of growth substrates (Maucieri *et al.*, 2019 & George and George, 2016) [25, 55]

Substrate	**Organic**	**Peat, Coconut Fibre**
	Inorganic	Sand, Pumice, Vermiculite, Perlite, Expanded Clay, Stone Wool
	Synthetic	Polystyrene, Polyurethane Foam

Table 8: Each growth substrate has its advantages and disadvantages based on the usage in the hydroponics system (Ashok and Sujitha, 2020) [5]

Substrates	Advantages	Disadvantages
Sand	Available in abundance less cost	Wastage of nutrients, salt accumulation, Regular sterilization is required
Vermiculite and Perlite	Lightweight 6-10 lbs/ft3	Vermiculite: Waterlogging is rapid, Perlite: Retained water is poorly permeated
Gravel	Inexpensive, Easy to clean, waterlogging is low	Heavy, Dries quickly
Rockwool (Volcanic Materials)	Lightweight, Simple to mould	Expensive, Algae growth is more
Saw Dust	High water retention, Lightweight, Adaptable to fertilizer	Tend to clot, Chemical cleaning is required, Susceptible to biological breakdowns
Brick Shards	Easy to use and recycle	Hard to use and must be scrubbed
Polyethene	Used in NFT system, Inexpensive	Very less root system

Table 9: Chemical - physical characteristics of inorganic substrates (Enzo *et al.*, 2004) [23]

Substrates	Bulk density (kg m^{-3})	Total porosity (% vol)	Free porosity (% vol)	Water retention capacity (%)	CEC (meq %)	EC (mS cm^{-1})	pH
Sand	1400-1600	40-50	1-20	20-40	20-25	0.10	6.4-7.9
Pumice	450-670	55-80	30-50	24-32	-	0.08-0.12	6.7-9.3
Volcanic Tuffs	570-630	80-90	75-85	2-5	3-5	-	7.0-8.0
Vermiculite	80-120	70-80	25-50	30-55	80-150	0.05	6.0-7.2
Perlite	90-130	50-75	30-60	15-35	1.5-3.5	0.02-0.04	6.5-7.5
Expanded Clay	300-700	40-50	30-40	5-10	3-12	0.02	4.5-9.0
Rockwool	85-90	95-97	10-15	75-80	-	0.01	7.0-7.5
Polystyrene	6-25	55	52	3	-	0.01	6.1

Properties of a good growth media

Successfully plants are grown in a hydroponic system with suitable growth media, these growth media should have good properties such as

- It should be inert and non-reactive with nutrients
- Aeration and drainage should be good
- It should be manufactured by the industry
- Media should be Low in cost
- It should be eco friendly
- It should have at least 3 years of life span
- It should be recyclable
- Growth media should have neutral pH

Merits and demerits of soil-less vegetable cultivation

There various merits and demerits of this soilless culture, some of the major points are described below (Pradhan and Deo, 2019) [67].

Merits of soilless farming

Production augmentation

An increase in the yield using soilless vegetable cultivation will help offset the initial and any additional cost of the soilless vegetation. This technique increases the yield of vegetables by controlling growth elements such as nutrition, Oxygen, carbon dioxide, light, pH and temperature that helps to produce high-quality vegetables (Polycarpou *et al.*, 2005) [66].

Water control

In the soilless system water used for irrigation is accurately controlled *i.e.* less than 10% is used than that of conventional soil-based vegetable cultivation (Olympios and Choukr-Allah, 1999) [62]. This majorly reduces labour requirement and frequent supervision of drippers or nozzles for calcium carbonate blockage is necessary.

Plant nutrition monitoring

In the nutrient solution, certain elements at higher concentration cause the death of plants, hence essential elements are added with appropriate concentration with the required pH and EC to improve the plant growth.

Purge practices and root surroundings

The soilless vegetable cultivation is usually done under a controlled environment, this helps to avoid the spread of diseases, pest and the growth of weeds (Manzocco *et al.*, 2011) [51]. The root environment can be modified efficiently due to the absence of soil.

Crop diversity

In the limited place, we can grow various types of vegetables with the periodic interval of time due to fewer cultivation operations. Therefore, multiple crops can be cultivated to get more income.

Land requirement

Vegetables can be grown in any places like on the roof, balcony, terrace of the building, stores etc as they are independent of the soil.

Climate control

In the soilless system of vegetable cultivation, all climatic factors such as temperature, pH, light, humidity and composition of air can be monitored efficiently as it is grown in greenhouses regardless of the season.

Better growth rate
Due to the cultivation of the vegetables under a controlled environment growth rate is better than the conventional soil cultivation. The absence of weed growth enhances the quality and yield of vegetable crops.

Increase in plant nutritional content
Through a hydroponic system, plant nutritional content can be enhanced by increasing the desired nutritional concentration of a specific element. The iodine content of salad crops like sweet basil and lettuce are enhanced by the addition of 10 μM of Potassium Iodide in the nutritional solution to provide Recommended Iodine Dosage to human through their diet by iodine biofortified basil and lettuce leaves (Puccinelli *et al.*, 2021) [69].

Less insecticide and herbicides
Very quantity of chemicals such as insecticides and herbicides that cause residual effect in the vegetable crops are used in soilless culture when compared to conventional cultivation. This majorly reduces the intensified labour involvement in cultivation, spraying, tilling, watering and weeding (Jovicich *et al.*, 2005) [40].

Demerits of soilless farming
High capital investment
Commercial cultivation of vegetable crops through soilless farming requires huge capital investment (Resh, 2013) [74].

Technicians and skilled labours
Soilless culture is an advanced and modern technology-based vegetable cultivation that requires skilled labours to handle these modernized equipment's.

Pathogenic injuries
The nutrient solution is circulated regularly to all plants and excess water is collected back in the tank. In this closed system once a plant gets affected by a pathogen it's very difficult to eradicate and it gets transmitted rapidly to other healthy plants (Ikeda *et al.*, 2001) [34].

Water and electricity
Successful soilless vegetable farming is achieved by proper water and electricity supply to the automated devices. Power failure and fewer water source may cause the failure of commercial farming under greenhouses.

Future thrust of soilless farming of vegetables
Soilless farming of vegetables is rapidly growing due to overpopulation and modern civilization that causing a decrease in arable fertile lands day by day. This situation could be overcome by following advanced cultivation technologies like hydroponics, aeroponics and aquaponics. Hydroponics has been successfully followed in Israel by cultivating various vegetables with less requirement of water. OrganiTech is an Israel based hydroponic company growing vegetables and other crops (berries, citrus and bananas) successfully inside shipping containers of 12.19 m (40 foot) this provide a better yield by 1000 times than conventional cultivation (Jain *et al.*, 2019) [35]. These shipping containers could be transported throughout the country. Efficient soilless cultivation can feed millions of people in areas where land and water are scarce *viz*. Asia and Africa.
In Tokyo, due to the surging population to feed the huge population, the country turned rice cultivation through a hydroponics system (De Kreij *et al.*, 2003) [20]. Under this system, rice is harvested in underground structures with a controlled environment where 4 cycles of harvest are achieved annually instead of a single harvest traditionally (Van Os *et al.*, 2002) [94].
Hydroponics cultivation of vegetable crops will be more important in the future for various space programs. NASA has wide-ranging research programs in beneficial space exploration and also long-term colonization on Mars or the moon (Van Os *et al.*, 2002) [94]. Since soil is the major lacking component in these planets and also very difficult to transport soil in space shuttles, the soilless farming technique could be a breakthrough in producing plants (vegetables, fruits, herbs) in space for the future colonizing humans. By this bioregenerative support system, plants are made to absorb carbon dioxide and release oxygen through the photosynthesis process for the habitation of both space stations and other planets (Singh and Singh, 2012) [81].

Conclusion
The human population is increasing and is predicted to expand from 7.0 billion to 9.5 billion people within the next 40 years. A parallel increase in the demand for food is implied, and estimates claim that food production will need to be doubled to compensate (Yeang and Pawlyn, 2009) [95]. By 2050, scientists estimate that the Earth's population will increase to 9.2 billion, while land available for crop and food production will decline. To feed the increasing population Soilless farming through hydroponics is extending worldwide and such systems offer many new opportunities to growers and consumers, to produce high-quality vegetables enhanced with bioactive compounds by replacing traditional farming. As it is possible to cultivate various vegetables like tomato, green leafy vegetables, cucumber, herbs, etc in places with less space and labour requirement, so hydroponics can play a great contribution to the poorer and landless people. Besides, it can improve the lifestyle of people and enhance the economic growth of a country by promoting innovative entrepreneurs to get involved in hydroponic farming. 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 start-up and operational costs. However, Government intervention and Research Institute interest can propel the use of this technology.
Hence, from the above literatures it could be concluded that there is extensive advance has been made as of late in the improvement of monetarily suitable soilless systems and there is a generally wide business application now in many countries that applied for farming innovations.

Reference

1. Adrover Maria, Gabriel Moyà, Jaume Vadell. Use of hydroponics culture to assess nutrient supply by treated wastewater. Journal of environmental management 2013;127:162-165.
2. Aquastat, FAO. FAO's global information system of water and agriculture 1999.
3. Arano Carlos R. Hidroponía: Algunas páginas de su historia. Horticultura internacional 2007;58:24-33.
4. Asao Toshiki. Hydroponics: A Standard Methodology for

Plant Biological Researches: BoD-Books on Demand 2012.
5. Ashok AD, Sujitha E. Hydroponic vegetable cultivation. International Journal of Chemical Studies 2020;8(5).
6. Azad KN, Salam MA, Azad KN. Aquaponics in Bangladesh: current status and future prospects. Journal of Bioscience Agriculture Research 2016;7(02):669-677.
7. Ban, Byunghyun, Janghun Lee, Donghun Ryu, Minwoo Lee, Tae Dong Eom. Nutrient Solution Management System for Smart Farms and Plant Factory. International Conference on Information and Communication Technology Convergence (ICTC) 2020.
8. Barbosa, Guilherme Lages, Francisca Daiane, Almeida Gadelha, Natalya Kublik, Alan Proctor *et al*. Comparison of land, water, and energy requirements of lettuce grown using hydroponic vs. conventional agricultural methods. International journal of environmental research public health 2015;12(6):6879-6891.
9. Barta, Daniel J, Keith Henderson. Use of Hydrogen Peroxide to Disinfect Hydroponic Plant Growth Systems. 4th Annual Conference on Life Support and Biosphere Science 2000.
10. Baudoin WO, Winsor GW, Schwarz M. Soilless culture for horticultural crop production: FAO 1990.
11. Bayat, Leyla, Mostafa Arab, Sasan Aliniaeifard, Mehdi Seif, Oksana Lastochkina *et al*. Effects of growth under different light spectra on the subsequent high light tolerance in rose plants. AoB Plants 2018;10(5):052.
12. Bindraban, Prem S, Marijn van der Velde, Liming Ye, Maurits Van den Berg, Simeon Materechera *et al*. Assessing the impact of soil degradation on food production. Current Opinion in Environmental Sustainability 2012;4(5):478-488.
13. Burrage SW. Soilless culture and water use efficiency for greenhouses in arid, hot climates. International Workshop on Protected Agriculture in the Arabian Peninsula, Doha (Qatar) 1998.
14. Butler, Jackie Dean, Norman Fred Oebker. Hydroponics as a hobby: growing plants without soil. University of Illinois, College of Agriculture, Extension Service in Agriculture and Home Economics 1962.
15. Çalişkan, Betül, Ali Cengiz Çalişkan. Potassium Nutrition in Plants and Its Interactions with Other Nutrients in Hydroponic Culture. In Improvement of Quality in Fruits and Vegetables Through Hydroponic Nutrient Management, 9-22. Books on Demand, Intech Open London 2019.
16. Castaño, Santiago Bonachela, Acuña RA, Magán Cañadas JJ, Malfa O. "Oxygen enrichment of nutrient solution of substrate-grown vegetable crops under Mediterranean greenhouse conditions: oxygen content dynamics and crop response." Spanish Journal of Agricultural Research 2010;4:1231-1241.
17. Chun, Changhoo, Tadashi Takakura. Rate of root respiration of lettuce under various dissolved oxygen concentrations in hydroponics. Environment Control in Biology 1994;32(2):125-135.
18. Cooper A. Growth and development of Komatsuna (*Brassica rapa* L. Nothovar) in NFT (nutrient film technique) system, as influenced by natural mineral. In The ABC of NFT (Nutrient Film Technique), 3-123. London (UK) Grower Books 1988.
19. Cuba, Renata da Silva, João Rios do Carmo, Claudinei Fonseca Souza, Reinaldo Gaspar Bastos. Potencial de efluente de esgoto doméstico tratado como fonte de água e nutrientes no cultivo hidropônico de alface. Revista Ambiente Água 2015;10(3):574-586.
20. De Kreij C, Voogt W, Baas R. Nutrient solutions and water quality for soilless cultures. Applied Plant Research, Division Glasshouse 2003.
21. Domingues, Diego S, Hideaki Takahashi W, Carlos Camara AP, Suzana Nixdorf L. Automated system developed to control pH and concentration of nutrient solution evaluated in hydroponic lettuce production. Computers electronics in agriculture 2012;84:53-61.
22. El-Kazzaz KA, El-Kazzaz AA. Soilless agriculture a new and advanced method for agriculture development: an introduction. Agricultural Research and Technology 2017;3:63-72.
23. Enzo, Massimo, Giorgio Gianquinto, Renzo Lazzarin, Pimpini F, Sambo P. Principi tecnico-agronomici della fertirrigazione e del fuori suolo, Tipografia-Garbin, Padova, Italy: Edito da Veneto Agricoltura 2004.
24. Ferrarezi, Rhuanito Soranz, Roberto Testezlaf. Performance of wick irrigation system using self-compensating troughs with substrates for lettuce production. Journal of Plant Nutrition 2016;39(1):147-161.
25. George, Philomena, Nirmal George. Hydroponics - (Soilless Cultivation of Plants) For Biodiversity Conservation. International Journal of Modern Trends in Engineering and Science 2016;3(6):97-104.
26. Gibson, James L. Nutrient deficiencies in bedding plants: A pictorial guide for identification and correction 2007.
27. Gislerød HR, Adams P. Diurnal variations in the oxygen content and acid requirement of recirculating nutrient solutions and in the uptake of water and potassium by cucumber and tomato plants. Scientia Horticulturae 1983;21(4):311-321.
28. Göhler, Frank, Heinz-Dieter Molitor. Erdelose Kulturverfahren im Gartenbau: 111 Tabellen: Ulmer 2002.
29. González Carmona, Emma, Cynthia Itzel Torres Valladares. La sustentabilidad agrícola de las chinampas en el Valle de México: caso Xochimilco. Revista Mexicana de agronegocios 2014;34, 1345-2016-104445.
30. Gruda, Nazim. Do soilless culture systems have an influence on product quality of vegetables? Journal of Applied Botany and Food Quality 2009.
31. Halveland, Julie. Design of a Shallow-Aero Ebb and Flow Hydroponics System and Associated Educational Module for Tri Cycle Farms. Bachelor of Science in Biological Engineering, Biological and Agricultural Engineering 2020.
32. Hoagland, Dennis Robert, Daniel Israel Arnon. The water-culture method for growing plants without soil. Circular. California agricultural experiment station 347 (2nd edit) 1950.
33. Hussain, Aatif, Kaiser Iqbal, Showket Aziem, Prasanto Mahato AK. "A review on the science of growing crops without soil (soilless culture)- A novel alternative for growing crops. International Journal of Agriculture Negi, and Crop Sciences 2014;7(11):833.
34. Ikeda, Hideo, Prommart Koohakan, Tanimnun Jaenaksorn. Problems and countermeasures in the re-use of the nutrient solution in soilless production. International Symposium on Design and Environmental Control of Tropical and Subtropical Greenhouses 2001,

578.
35. Jain, Ankita, Nidhi Kumari, Vikash Kumar Jha. A review on hydroponic system: hope and hype. Recent Advances in Chemical Sciences Biotechnology 2019, 143.
36. Javaid Afra. Hydroponics and its applications: Here's everything you need to know 2020. https://www.jagranjosh.com/general-knowledge/hydroponics-and-its-applications-1608551140-1.
37. Jensen Merle H. Hydroponics worldwide. International Symposium on Growing Media and Hydroponics 1997, 481.
38. Jones JB. Hydroponic cropping. CRC Press 2005.
39. Jones Jr, Benton J. Hydroponics: a practical guide for the soilless grower: CRC press 2016.
40. Jovicich Elio, Cantliffe DJ, Simonne EH, Stoffella PJ. Comparative water and fertilizer use efficiencies of two production systems for cucumbers. III International Symposium on Cucurbits 731 2005.
41. Kim, Jae Kyung, Dong Cheol Jang, Ho Min Kang, Ki Jung Nam, Mun Haeng Lee *et al*. Effects of Light Intensity and Electrical Conductivity Level on Photosynthesis, Growth and Functional Material Contents of Lactuca indica L.'Sunhyang'in Hydroponics. Protected Horticulture Plant Factory 2021;30(1):1-9.
42. Klinger, Dane, Rosamond Naylor. Searching for solutions in aquaculture: charting a sustainable course. Annual Review of Environment Resources 2012; 37:247-276.
43. Koohakan, Prommart, Tanimnun Jeanaksorn, Itthisuntorn Nuntagij. Major diseases of lettuce grown by commercial nutrient film technique in Thailand. Current Applied Science Technology 2008;8(2):56-63.
44. Kubiak, Katarzyna, Mieczysław Błaszczyk, Zbigniew Sierota, Miłosz Tkaczyk, Tomasz Oszako. Slow sand filtration for elimination of phytopathogens in water used in forest nurseries. Scandinavian Journal of Forest Research 2015;30(8):664-677.
45. Lakshmanan, Ravi, Mohamed Djama, Sathish Kumar Selvaperumal, Raed Abdulla J. Automated smart hydroponics system using internet of things. International Journal of Electrical Computer Engineering 2020;10(6):6389-6398.
46. Lee, Seungjun, Jiyoung Lee. Beneficial bacteria and fungi in hydroponic systems: Types and characteristics of hydroponic food production methods. Scientia Horticulturae 2015;195:206-215.
47. Libia I, Trejo T, Fernando C, Gomez M. Nutrient solution for hydroponic systems, book Hydroponics-a standard methodology for plant biological researches by Toshiki Asao: In Tech com 2012.
48. Liu, Shuyuan, Yinglong Hou, Xu Chen, Yuan Gao, Hui Li, Shujuan Sun. Combination of fluconazole with non-antifungal agents: a promising approach to cope with resistant Candida albicans infections and insight into new antifungal agent discovery. International journal of antimicrobial agents 2014;43(5):395-402.
49. Liu, Xingda, Guanqun Wang, Jianmin Gao. Experimental study of ultrasonic atomizer effects on values of EC and pH of nutrient solution. International Journal of Agricultural Biological Engineering 2018;11(5):59-64.
50. Maharana L, Koul DN. The emergence of Hydroponics. Yojana 2011;55:39-40.
51. Manzocco, Lara, Martina Foschia, Nicola Tomasi, Michela Maifreni, Luisa Dalla Costa *et al*. Influence of hydroponic and soil cultivation on quality and shelf life of ready- to- eat lamb's lettuce (*Valerianella locusta* L. Laterr). Journal of the Science of Food Agriculture 2011;91(8):1373-1380.
52. Marschner HJ. London, UK. Mineral nutrition of higher plants. Academic Press 1995, 158-168.
53. Marschner, Horst. Marschner's mineral nutrition of higher plants: Academic press 2011.
54. Masclaux-Daubresse, Céline, Françoise Daniel-Vedele, Julie Dechorgnat, Fabien Chardon, Laure Gaufichon *et al*. Nitrogen uptake, assimilation and remobilization in plants: challenges for sustainable and productive agriculture. Annals of botany 2010;105(7):1141-1157.
55. Maucieri, Carmelo, Carlo Nicoletto, Erik Van Os, Dieter Anseeuw, Robin Van Havermaet *et al*. Hydroponic technologies. Aquaponics food production systems 2019, 77.
56. McCutchan Jr, James H, William Lewis M Jr, Carol Kendall, Claire McGrath C. Variation in trophic shift for stable isotope ratios of carbon, nitrogen, and sulfur. Oikos 2003;102(2):378-390.
57. Morard P, Silvestre J. Plant injury due to oxygen deficiency in the root environment of soilless culture: a review. Plant soil 1996;184(2):243-254.
58. Morgan, Lynette. Nutrient Film Technique (NFT) Production of Lettuce. Diakses dr 2009. www.Cropking. com/NFTlettuce.html.
59. Muneer, Sowbiya, Bok-Rye Lee, Kil-Yong Kim, Sang-Hyun Park, Qian Zhang *et al*. Involvement of sulphur nutrition in modulating iron deficiency responses in photosynthetic organelles of oilseed rape (*Brassica napus* L.). Photosynthesis research 2014;119(3):319-329.
60. Nosir, Walid. New technique for rose production in soilless culture system and disease reduction. Journal of Plant Nutrition 2016;39(2):181-188.
61. Ohtani, Toshio, Akiko Kaneko, Naoya Fukuda, Shoji Hagiwara, Sadanori Sase. SW-Soil and Water: Development of a membrane disinfection system for closed hydroponics in a greenhouse. Journal of agricultural engineering research 2000;77(2):227-232.
62. Olympios CM, Choukr-Allah R. Overview of soilless culture: advantages, constraints, and perspectives. Protected cultivation in the Mediterranean region 1999;31:307-324.
63. Papadopoulos AP, Hao X, Tu JC, Zheng J. Tomato production in open or closed rockwool culture systems with NFT or rockwool nutrient feedings. International Symposium on Growing Media and Hydroponics 1997, 481.
64. Patil ST, Kadam US, Mane MS, Mahale DM, Dhekale JS. Hydroponic Growth Media (Substrate): A Review. International Research Journal of Pure Applied Chemistry 2020, 106-113.
65. Pinho, Sara Mello, Diego Molinari, Giovanni Lemos de Mello, Kevin Fitzsimmons M, Maurício Gustavo Coelho Emerenciano. Effluent from a biofloc technology (BFT) tilapia culture on the aquaponics production of different lettuce varieties. Ecological Engineering 2017;103:146-153.
66. Polycarpou P, Neokleous D, Chimonidou D, Papadopoulos I. A closed system for soil less culture adapted to the Cyprus conditions. Proceedings of the ICID Conference 2005.

67. Pradhan, Bikram, Bandita Deo. Soilless farming-the next generation green revolution. Current Science 2019;116(5).
68. Pregitzer KS, King JS. Effects of soil temperature on nutrient uptake. In Nutrient acquisition by plants 2005, 277-310. Springer.
69. Puccinelli M, Landi M, Maggini R, Pardossi A, Incrocci L. Iodine biofortification of sweet basil and lettuce grown in two hydroponic systems. *Scientia Horticulturae* 2021;276:109783.
70. Rakocy, James. Ten guidelines for aquaponic systems. Institute of Food and Agricultural Sciences and University of Florida 2007.
71. Rakocy, James E. Aquaponics: integrating fish and plant culture. Aquaculture production systems 2012;1:343-386.
72. Rakocy, James, Michael Masser P, Thomas Losordo. Recirculating aquaculture tank production systems: aquaponics-integrating fish and plant culture 2016.
73. Rana S, Bag SK, Golder D, Mukherjee Roy S, Pradhan C, Jana BB. Reclamation of municipal domestic wastewater by aquaponics of tomato plants. Ecological Engineering 2011;37(6):981-988.
74. Resh, Howard. Hobby hydroponics: CRC Press 2013.
75. Rooney, Corinne P, Fang‐ Jie Zhao, Steve McGrath P. Soil factors controlling the expression of copper toxicity to plants in a wide range of European soils. Environmental Toxicology Chemistry: An International Journal 2006;25(3):726-732.
76. Sago Y, Yasutake D, Miyauchi K, Affan FFM, Ochi M, Imai M *et al*. Energy-saving temperature control of nutrient solution in soil-less culture using an underground water pipe. International Workshop on Greenhouse Environmental Control and Crop Production in Semi-Arid Regions 2008, 797.
77. Salisbury, Frank B, Ross CW. Plant Physiology. Wadsworth Publishing Co: Inc. California 1992.
78. Sardare, Mamta D, Shraddha Admane V. A review on plant without soil-hydroponics. International Journal of Research in Engineering Technology 2013;2(3):299-304.
79. Savvas, Dimitrios, Harold Passam. Hydroponic production of vegetables and ornamentals: Embryo publications Athens 2002.
80. Sharma, Nisha, Somen Acharya, Kaushal Kumar, Narendra Singh, Chaurasia OP. Hydroponics as an advanced technique for vegetable production: An overview. Journal of Soil Water Conservation 2018;17(4):364-371.
81. Singh S, Singh BS. "Hydroponics-A technique for cultivation of vegetables and medicinal plants. Proceedings of 4th Global conference on Horticulture for Food, Nutrition and Livelihood Options. Bhubaneshwar, Odisha, India 2012.
82. Son, Jung Eek, Hak Jin Kim, Tae In Ahn. Hydroponic systems. In Plant factory. Elsevier 2020, 273-283.
83. Sonneveld, Cees, Wim Voogt. Plant nutrition in future greenhouse production. In Plant nutrition of greenhouse crops. Springer 2009, 393-403.
84. Steiner, Abram A. The influence of the chemical composition of a nutrient solution on the production of tomato plants. Plant Soil 1966;24(3):454-466.
85. Steiner, Abram A. A universal method for preparing nutrient solutions of a certain desired composition. Plant soil 1961;15(2):134-154.
86. Sutton JC, Yu H, Grodzinski B, Johnstone M. Relationships of ultraviolet radiation dose and inactivation of pathogen propagules in water and hydroponic nutrient solutions. Canadian Journal of Plant Pathology 2000;22(3):300-309.
87. Taiz, Lincoln, Eduardo Zeiger. Plant Physiology. Sunderland, Massachusetts 1998;277.
88. Trejo-Téllez, Libia I, Fernando Gómez-Merino C. Nutrient solutions for hydroponic systems. Hydroponics-a standard methodology for plant biological researches 2012, 1-22.
89. Turner, Bambi. How Hydroponics Work 2008. Retrieved November 18: 2008.
90. Urrestarazu M. Tratado de cultivo sin suelo Mundi Prensa Libros. España 2004.
91. Urrestarazu, Miguel, Pilar Carolina Mazuela. Effect of slow-release oxygen supply by fertigation on horticultural crops under soilless culture. Scientia Horticulturae 2005;106(4):484-490.
92. Van Labeke, Marie-Christine, Dambre P, Schrevens E, De Rijck G. Optimisation of the nutrient solution for Eustoma grandiflorum in soilless culture. International Symposium on Growing Media & Plant Nutrition in Horticulture 1994, 401.
93. Van Os EA. Comparison of some chemical and non-chemical treatments to disinfect a recirculating nutrient solution. International Symposium on Soilless Culture and Hydroponics 2008, 843.
94. Van Os EA, Th Gieling H, Ruijs MNA. Hydroponic production of vegetables ornamentals, Equipment for hydroponic installations: Embryo Publications, Athens, Greece 2002.
95. Yeang Ken, Michael Pawlyn. Seawater Greenhouses and the Sahara Forest Project. Architectural Design 2009;79(4):122-123.
96. Zheng J, Sutton JC, Yu Hi. Interactions among Pythium aphanidermatum, roots, root mucilage, and microbial agents in hydroponic cucumbers. Canadian Journal of Plant Pathology 2000;22(4):368-379.