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REVIEW

Hydroponics: current and future state of the art in farming

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ABSTRACT
Today, to overcome the multi-manifestations of climate change, fresh water scarcity, and pressing need of the growing food demand, Hydroponics, a soilless cultivation technology, promises to provide high quality, healthy, fresh, residue free vegetables and fruits locally. This review paper provides an insight into the field of hydroponics, its benefits and setbacks. It also highlights the expertise required for undertaking hydroponics cultivation "along with the current trend prevailing in it and with an overview of the major companies dealing in the same".

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Introduction

World population is projected to reach 9.7 billion by 2050. At the same time, it has been estimated that 50% of the arable land around the world will be unusable for farming (U. Nation 2017). Consequently, the food production will need to be increased by 110% to meet the high demand. As the world population grows, the demand and need for different products, especially food products, grows as well. Because of this growing demand, a food crisis is expected in the coming years. To prevent such crisis from happening, farming methods must be improved, and sources of food must be used efficiently (Raneem et al. 2018). Current farming practices are fundamentally are based on soil, water and is prone to failure due to erratic climate conditions; henceforth, there is a need to change and develop the economic policies of current farming systems. The demand for food is implied, and estimates claim that food production will need to be doubled in order to compensate (The Sahara Forest Project, 2009). To make matters worse, the affluence of the world is increasing, meaning that more of the future's consumers will demand higher quality resources (Charles and Godfray 2011). However, in many developing countries, urbanization process is characterized with increasing urban poverty and polluted environment, growing food insecurity and malnutrition, especially for children, pregnant and lactating women; and increasing unemployment (Orsini et al. 2013). Agriculture is arguably one of the most important industries in the world. Unfortunately, agriculture is also one of the most unpredictable industries, subject to the whims of nature with incidence of droughts, fire, flood, hail etc. In fact, 90 percent of all crop loss is caused by weather, according to the U.S. Department of Agriculture (Orsini et al. 2013).

A significant decline in agricultural output will trigger a disproportionate rise in prices and an increase in total revenue expenditure, a phenomenon that is well documented. Due to rapid urbanization and industrialization as well as melting of icebergs (as an obvious impact of global warming), arable land under cultivation is further going to decrease. Again, soil fertility status has attained a saturation level, and productivity is not increasing further with increased level of fertilizer application (Sengupta and Banerjee 2012).

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What is hydroponics

Hydroponics is the art and science of growing crops in a soil-less manner. In hydroponics, plants are grown without soil by providing them with nutrient-rich solutions in water solvent, which the plants conventionally obtain from the soil in traditional farming. The main objective of hydroponics is to supply the ideal nutritional environment for optimum plant performance, further optimized by controlling the climate. In conventional farming, soil is only the container of the nutrients; it is a place where the plant roots traditionally live and a base of support for the plant structure (Somerville, et al., 2014). Interest in hydroponic culture has continued for several reasons. Firstly, no soil is needed, and a large plant population can be grown in a very small area. Secondly, when fed effectively, optimum production can be attained (Deutschmann 1998; Saffell 1993). Thirdly, nutrients, water, and aeration can be controlled to the highest degree. This level of control is hard to match in solid media. Today, hydroponics is an established branch of agronomic science (Steinberg et al. 2000).

In agriculture yield-related water use efficiency can be increased by three main ways: (i) increase the physiological and transpirational efficiencies, by manipulating the environment (greenhouse, soilless culture) in order to get a faster growth and development with the same amount of transpired water. (ii) reduce the evaporation component, by mulching, or by using artificial substrates in containers or bags, that significantly reduce the area of evaporating soil and (iii) reduce the water loss due to drainage and run-off, by recycling part of or totality of the nutrient solution (Balliett 2007). The greenhouse systems that use hydroponics are considered to be superior to field production systems in terms of water and nutrient-use efficiencies (Bradley and Marulanda, 2001). However, the efficiency of the hydroponics-based system greatly depends on its design and the way the water and nutrient solutions are managed. Hydroponic systems are ideal for recycling water and nutrients because the drained solution can be easily captured for reuse. Greenhouse crops grown in closed hydroponic systems can substantially reduce the pollution of water resources, while contributing to a reduction in water and fertilizer consumption (Carmassi et al. 2005; Bar-Yosef 2008). The recycling of the nutrient solution does not restrict crop yields (Zekki, Gauthier, and Gosselin 1996; Raviv et al. 1998).

Hydroponics is a flexible technology, apt for developing countries, like India, and high-tech space stations. Hydroponics is NASA's solution to providing space travelers with a self-sufficient food source. The NASA administration has sponsored a research programmer titled *Controlled Ecological Life support system* (CELSS) in order to further develop the technology and carry it into space in the future (Roberto 2003). NASA has a list of 15 plants, grown using hydroponics that will save our life. Plants offer a promising solution in providing food to astronauts thousands of miles from Earth.

They could grow crops that would not only supplement a healthy diet but also remove toxic carbon dioxide from the air inside their spacecraft and create life-sustaining oxygen. Inside closed plant growth chambers at Kennedy Space Centre, radishes, lettuce, and green onions grown "hydroponically" in nutrient-enriched solution. Light, temperature, and carbon dioxide levels are controlled carefully (Heiney 2004).

Hydroponic technology efficiently generates crops in deserts, infertile lands, in mountainous regions, on city rooftops, and concrete schoolyards. Like manufacturing, agriculture should adopt advancements of technology, thus providing novel solutions to ongoing challenges. Hydroponics is highly productive and fit for automation. Plant factories have highly controlled environments, with a degree of control far higher than greenhouses where soil is replaced with non-soil materials and nutrients are obtained from water rich nutrients (Wang 2011). Hydroponics is popular not just as a way to produce larger, healthier, and more flavorful foods on a large scale, but also as a household hobby. Simple hydroponic systems can help people grow herbs, flowers, or vegetables in their basements, in a large closet or even on their kitchen counter. In the future hydroponics may become the only way by which food crops and medicinal plants can be grown to sustain the earth. Thus, hydroponics is the future of farming.

History of hydroponics

The word hydroponics comes from two Greek words 'hydro' meaning water and 'ponos' meaning labor. This word was first used in 1929 by Dr. Gericke, a California professor who began to develop what previously had been a laboratory technique into a commercial means of growing plants (Jones 2014). The U.S. Army used hydroponic culture to grow fresh food for troops stationed on infertile Pacific islands during World War II. By the 1950s, there were viable commercial farms in America, Europe, Africa and Asia. In 1990, there was a boom in hydroponic cultivation such as in space programmes, growing plants in deserts, polar regions, vertical farming and in large scale production (Jones 2014).

Components of hydroponics

Water

For hydroponics Reverse osmosis (RO) water is used with no to less total dissolved salts (TDS) so that (salts) can be added according to crop and stage of plant.

Nutrients

One of the basic principles for vegetable production, both in soil and in hydroponic systems, is to provide all the nutrients the plant needs. Several chemical elements are essential for growth and production of plants. Plants are cultivated in highly oxygenated, nutrient enriched water, without the use of soil. The management of nutrient solution is the cornerstone for a successful hydroponic system (Aviles and Light 2018, Sato et al. 2006). The hydroponic nutrient solution is required to supply the plant roots with water, oxygen and essential mineral elements in soluble form.

The biological decomposition breaks down organic matter into basic nutrients in the soil that feeds plants. Water then dissolves these nutrients which then is absorbed by the roots. To provide plants a well-balanced diet, everything in the soil should be in its perfect form. There are seventeen elements that are required for the proper growth of plants. For growth of plants, nine of these are Carbon (C), Hydrogen (H), Oxygen (O_2), Sulfur (S), Phosphorus (P), Calcium (Ca), Magnesium (Mg), Potassium(K) and Nitrogen (N) are required in large amounts and hence are called as macro nutrients. The remaining eight elements which are known as macronutrients such as Iron (Fe), Zinc (Zn), Copper (Cu), Manganese (Mn), Boron (B), Chlorine (Cl), Cobalt (Co) and Molybdenum (Mo) are needed in small amounts (Sato et al., 2006; Malavolta 2006). Most recommendations of nutrient solutions are based on the early work of Hoagland and Arnon (1938). There can be a significant difference in the cost, purity, and solubility of the chemicals comprising a nutrient solution, depending on the grade (pure, technical, food, or fertilizer) used. Smaller operations often buy ready-mixed nutrient formulations to which only water need be added to prepare the nutrient solution. Larger facilities prepare their own solutions to standard or slightly modified formulae.

A complete description of nutrient solution formula, mixing, etc., is in an article published by Jensen and Collins in 1985. In all hydroponic systems nutrient elements are mixed in specific solutions and in the amounts and proportions required by various plants. The solution is brought into direct contact with the plant roots (Trejo-Téllez and Gómez-Merino, 2012). Nutrients play a key role in the quality and productivity of vegetables and fruits. Thus, the balanced application of nutrients is vital in determining the quality of the product (Abou-Hadid et al. 1996)

Table 1 represents the concentration range of nutrients in soil and soilless crop. Usually soilless media requires higher concentration of nutrients than soil media (Table 2).

Table 1. Comparative concentration ranges of macronutrients (mM) in soil and soilless crops.

Nutrients	Soil (mM)	Hydroponics (mM)
N-NO_3^-	0.5-10	5-20
N-NH_4^+	0.02-0.05	0.5-2
P($H_2PO_4^-$)	0.0005-0.05	0.5-2
K^+	0.2-2	5-10
Ca^{2+}	0.5-4	3-6
Mg^{2+}	0.2-2	1-2
S (So^{2-})	0.1-2	1.5-4

Source: (reworked by Epstein 1972; Marschner 1996)

Table 2. Major elements and micronutrients needed also their concentration range in most nutrient solutions.

Elements	Ionic form	Concentration range mg/l or ppm
Nitrogen(N)	NO_3^- , NH_4^+	100–200
Phosphorus (P)	$H_2PO_4^-$	30–15
Potassium (K)	K^+	100–200
Calcium (Ca)	Ca_2^+	200–300
Magnesium(Mg)	Mg_2^+	30–80
Sulfur (S)	So_4	70–150
Micronutrients		
Boron(B)	BO_3^-	0.03
Copper(Cu)	Cu^{2+}	0.01–0.10
Iron(Fe)	Fe^{2+}, Fe^{3+}	2–12
Manganese (Mn)	Mn^{2+}	0.5–2.0
Molybdenum (Mo)	Mo^{2-}	0.5
Zinc (Zn)	$Zn2^+$	0.5–0.50

Electrical conductivity (EC)

EC of cultivable soil is restricted to <4 dS m^{-1}. In soilless culture, the various media used may exhibit varied EC values based on the admixtures and source from which the media are procured. The EC of organic substrates is always higher than that of inorganic substrates. Among the organic substrates, the highest EC value was obtained from Peat (1.065 dS m^{-1}) and followed by Peat moss (0.706 dS m^{-1}) (Bunt 1988, Abad et al. 2002). For tomato at EC above 4–6 dS m^{-1}, plants have a significantly restricted water uptake (Cuartero and Fernandez-Munoz, 1998). Athanasious et al. (2005) observed significant EC (approximately 3.5 dS m^{-1}) effects on tomato root growth and marketable yield when grown on Rockwool. Magan et al. (2008) evaluated the effect of salinity on fruit yield, yield components, and fruit quality of tomato grown in soilless culture in plastic greenhouses. Total and marketable yield decreased linearly with increasing salinity above a threshold EC value (EC_t).

pH

Besides physical properties of the media, chemical properties such as pH and electrical conductivity are important parameters for optimum growth of soilless crops. Recommended pH ranges for soilless media vary depending on crop species (Othman et al. 2019).

The chemical composition of media particles, the ratio of media components in the mix, and irrigation and fertilizer practices affect the pH of growing media. The pH is an important factor in the availability and uptake of nutrients. A satisfactory pH of the medium ranged between 5.5 and 6.5 (Waters, Flewellyn, and Smith 1970). Brown and Pokarny (1975) reported an increase in pH of pine bark from 4.1 to 5.4 with the addition of sand as pH of sand is 7 it helps in reducing the acidity. Basker and Saravanan (1997) reported that the pH of medium was reduced considerably by coco-coir addition. Coir pith lowered the EC from 3.2 to 0.7 dS m^{-1} in saline alkali soil. EC of the kenaf stem core containing media was reduced considerably by coco-coir addition. There is great variation in pH of the coir growing media with values ranging from 4.8 to 6.9. Generally, coir has low P content (Asiah et al. 2004). Coir also contains significant amounts of micronutrients, and these can also vary a great deal. CEC deals are high and are similar to peat (Maher, Prasad, and Raviv 2008).

Media

A good culture medium should be able to offer the plant the highest availability of water (i.e., have a good water retention capacity), but at the same time ensure sufficient aeration to the roots. In other words, there should be a balanced ratio between the microporosity (constituted by pores able to retain the water at the end of the drainage after complete saturation) and the macro porosity (porosity free, provided by all the pores that do not retain water and that are filled with air). Better Water:Air ratios are ensured by materials with high porosity (i.e., pore space by volume) (optimally 75%) and with the right balance between micro (40- 60%) and macro (15-35%) pores. With crops in small containers (e.g., quick pot), the total pore space is expected to reach 85 percent of the volume (Rosario et al. 2013). **Bulk density:** The bulk density (BD) affects the choice of media in different ways.

High Bulk density is achieved by the inclusion of heavy mineral constituents such as sand, soil, clay or tuff in the mix. On the other hand, high intensity greenhouse crops which frequently are irrigated, and may be exposed to oxygen deficiency if hydraulic conductivity and air filled porosity (AFP) are not high, require media of low bulk density (like Gravel has high bulk density and high aeration). Mixing and transport of low BD media are easy than those of high BD (Raviv and Lieth 2008). Quintero et al. (2009) studied the hydro-physical characteristics of burnt rice husks, coconut fiber and mixtures of both, in proportions of 35:65 and 65:35. Particle size distribution, solid, and bulk density, total porosity, air, and water distribution (easily, heavily, and reserve water, and saturated hydraulic conductivity) were analyzed for each substrate at several phenological stages of rose crops. The results showed values for solid density similar to those previously reported, ranging between 0.77 g cm^{-3} for burnt rice husks and 0.81 g cm^{-3} for the 65:35 mixtures. Bulk density is highest on burnt rice husks (0.26 g cm^{-3}) and lowest on coconut fiber (0.13 g cm^{-3}), mixtures show proportional intermediate values. Coconut fiber displayed bigger particle size (from >2.5 to 0.63 mm), whereas burnt rice husk has higher values of fine particle size (0.63 to <0.08 mm), and that fraction will increase with the crop's age. **Porosity**: In many cases, bulk density is inversely related to total porosity. The medium bulk density cannot accurately determine total porosity if components that have closed pores such as Perlite or Pumice are used (Bunt 1988). Most media and mixes have an air-filled porosity of 10-30 per cent. Lower air-filled porosity is required for bedding plants grown in shallow trays or plugs. For all types of media and containers, it is important to consider the tendency of most root systems to grow under the influence of gravity and to form a dense layer in the bottom (Raviv and Lieth 2008).

Light

Light is an important factor that influences growth of a plant by affecting photosynthesis, photorespiration, and photoperiodism. The optimum light intensity for most of the greenhouse vegetable crops is in the range of 50000–70000 lux. Light is a prerequisite for plant growth. The rate of photosynthesis is governed by the availability of nutrients, water, CO_2, light, and temperature. Considerable energy is required to reduce the carbon that is combined with O_2 in CO_2 gas to the state in which it exists in the carbohydrate. The light energy is thus utilized and trapped in the carbohydrate. If the light intensity is diminished, photosynthesis slows down and affects the growth. If higher optimal intensities are provided, the growth again slows down because of the injury to chloroplasts. Light plays a second role in photoperiodism, which is the response of plant during the day-night cycle. The relative temperature of daylight and dark periods governs a number of responses including leaf shape, stem elongation, flowering among other responses. Light is often a limiting factor in winter. Moon and Lee (1980) observed that short-day treatment of garlic plants resulted in suppression of growth, poor bulb formation and induction of secondary growth. Total sugar content was higher in plants grown in natural day length than these grown under short-day treatment. Loss of light has been a major concern in the greenhouse industry as it lowers photosynthesis rates may be due to shade. When photosynthetic photon flux density (PPFD) is low, it may result in limitation in yield and quality (Challa and Schapendonk 1984).

Wright and Sobeih (1986) observed that a high level of photosynthetically active radiation combined with a long photoperiod accelerated bulbing and final bulb size in onion. Plants will therefore benefit from more uniform distribution of irradiation throughout the canopy as lower light intensities are used more efficiently for photosynthesis than higher light intensities (Aikman 1989). Evapotranspiration is inversely proportional to the stomatal resistance of leaves, which in turn is strongly dependent on the light intensity on leaves. The temperature of leaves, and transfer of heat from leaves to the surrounding air by natural connection, is also directly related to the absorption of radiation by leaves. Therefore, light penetration into a crop stand is not only important component of plant growth but it is also essential factor that determines the microclimate in plant stands (Yang et al. 1990). The photosynthesis activity depends upon the light intensity and strongly increases with increase of luminosity. But, beyond a certain point, an further increase of luminosity does not make the photosynthesis activity increase any more (Zanon 1990). Boulard et al. (1991) reported that for well-watered plants, which are common situation in greenhouses, more than 70 percent of incoming radiation was used to evaporate water during the summer period. Either increased irradiance and higher air temperature accelerates the rate of development of the individual fruit and thereby increases the early yield (Marcelis, 1993a, 1993b). High light intensity improves fruit color and shelf life of greenhouse-grown cucumber through high chlorophyll content in the peel (Klieber et al. 1993). In order to attain good growth of plants, inside the greenhouse, there should be sunshine of desired quantity and intensity. The low intensity is the most important environmental restraint to maximize transpiration and growth. Opening and closing of stomata, there by transpiration, is affected by the light intensity (Bakker 1995). The greenhouse crops were subjected to light intensities varying from ~ 100,000 lux on clear summer days to 3200 lux on cloudy winter days. For most of the crops, neither of the extreme conditions was ideal, and many crops became light saturated. In other words, the rate of photosynthesis did not increase at light intensities below 32300 lux (Radha and Igathinathane 2000). With increase in light intensity, the rate of the light-dependent reaction, and therefore photosynthesis generally, increases proportionately (straight line relationship) The increase seems to be curvilinear not linear. A saturation in light intensity is reached. The more photons of light that fall on a leaf, the greater the number of chlorophyll molecules that are ionized and the more ATP and NADPH are generated. Light dependent reactions use light energy and so are not affected by changes in temperature. The wavelength of light is also important. PSI absorbs energy most efficiently at 700 nm and PSII at 680 nm thus the light with a higher proportion of energy concentrated in these wavelengths will produce a higher rate of photosynthesis (Kume, Akitsu, and Nasahara 2018).

Temperature

Although the light dependent reactions of photosynthesis are not affected by changes in temperature, the light independent reactions of photosynthesis are dependent on temperature. They are reactions catalyzed by enzymes (Kume, Akitsu, and Nasahara, 2018). As the enzymes approach their optimum temperatures the overall rate increases. It approximately doubles for every 10 °C increase in temperature. Above the optimum temperature the rate begins to decrease, as enzymes are denatured, until it stops in this way, temperature plays an important role on the vegetative, and photosynthetic activity of the plants. It affects the plant growth either by increasing or decreasing the rate of different plant process as photosynthesis, respiration, and transpiration. The maximum activity is obtained between 21-27 °C day temperatures under greenhouse for most of the vegetables (Kawasaki and Yoneda 2019).

In greenhouse, apart from light, air temperature is also the main environmental component influencing vegetative growth, cluster development, fruit setting, fruit development, fruit ripening, and fruit quality. The average 24-hour temperature is believed to be responsible for the growth rate of the crop-the higher the average air temperature, the faster the growth. It is also believed that the larger the variation in day-night air temperature, the taller the plant and the smaller the leaf size. Although maximum growth is known to occur at a day and night temperature of approximately 25˚C, in general maximum fruit production is achieved with a night temperature of 18 °C and a day temperature of 20˚C. The difference (DIF) between day temperature (DT) and night temperature (NT) influences internode length, plant height, leaf orientation, shoot orientation, chlorophyll content, lateral branching and petiole and flower stalk elongation in plants (Shimizu 2007). Internodal length increases as DIF increases. Most plants respond to a change in DT and NT within 24 h. In some long-day plants (LDP), DIF has only a minor influence on flower initiation. (Myster and Moe 1995). Ganesan (2002) reported that poly-greenhouse with ventilation gaps in the triangular roof and four sidewalls was more suitable for better plant growth and yield of tomato than the open field condition. The air temperature in the open field condition was lower than in the poly-greenhouse treatments throughout the growth period. A study was conducted in a polyhouse equipped with solar module aided spinning disk sprayer and solar energy aided exhaust fan. The crop response could be altered by achieving specific climatic conditions in the polyhouse. In the case of tomato, 96 per cent increase in shoot length and a 27 percent increase in yield were observed inside the polyhouse. For brinjal also known as egg plant, the shoot length increased by 55 percent and the yield increased by 85 per cent (Kavitha, Vijayaraghavan, and Tajuddin 2003).

Carbon dioxide

An increase in the CO_2 concentration, increases the rate at which carbon is incorporated into carbohydrate in the light-independent reaction, and so the rate of photosynthesis generally increases until limited by another factor (Boretti and Florentine 2019). As it is normally present in the atmosphere at very low concentrations (about 0.04%), increasing carbon dioxide concentration causes a rapid rise in the rate of photosynthesis, which eventually plateaus when the maximum rate of fixation is reached. Thus one can say that CO_2 concentration is directly proportional to the rate of photosynthesis.

Relative humidity

The control of relative humidity inside the green house is of most important as it influences the quality of plant. Standard relative humidity (RH) for most of the crop is 60-75 per cent. Mitchell and Hoff (1977) reported that the low ambient humidity had limited the growth and increased the water consumption by seedlings of tomato grown in peat blocks. The most harmful high humidity in closed greenhouses appears unexpectedly during the period of a few hours after sunrise, because solar radiation transmitted into the interior expedites the transpiration of crops (Mihara and Hayashi 1978). Rise in air humidity stimulates growth and photosynthesis and high humidity levels resulted in an increased photosynthetic rate (Bunce 1984). High humidity increased cucumber total yield, but did not affect the early yield (main stem fruit) fresh and dry weight, stem length and leaf area, and the final total cucumber yield was positively related to daytime humidity (Barker, Welles, and van Uffelen 1987). Gislerod, Selmer-Olsen, and Mortensen (1987) studied the effect of air humidity on nutrient uptake of some greenhouse plants. Young plants of nine different greenhouse species were grown for 24 to 100 days at 55–60, 70–75, and 90–95 percent relative humidity (RH) in growth rooms. They were given complete nutrient solution twice a week. Transpiration rate decreased significantly by increasing RH from the lowest to the highest level. The content of macronutrient elements in the plant leaves decreased by increasing RH. The content of the macro nutrient elements in the growth medium at the end of the experiment was lowest when the plants had been growing at high RH. The elements mainly affected were N and K. Humidity level inside the naturally ventilated greenhouses was very low due to over ventilation (Arbel et al., 1990). Inside the greenhouse a relative humidity of 70 to 80 percent can be regulated as being within a safe range (Jolliet et al. 1993). Plants, which are maintained continuously under high humidity conditions, may exhibit soft, mushy rotted leaf and stem tissue (Prasad 1997). Normal plant growth will occur at relative humidity 25-80 percent, and the growth is correlated positively to the relative humidity. But too high relative humidity is also harmful for plants because most pathogenic spores germinate at high relative humidity (Zhen et al. 2016). Ganesan (2002) studied the effect of changes in microclimate produced by poly greenhouse conditions on plant growth characteristics and fruit yield of tomato during 1999 in Tamil Nadu. UV-stabilized plastic film covered greenhouse recorded higher day temperature than the open environment but relative humidity at 8.00 am was lower inside the greenhouse except from May to August. The light intensity inside the greenhouse was lower than in the open. Height of the plant, number of nodes, internodal length total dry matter production and average fruit weight increased under greenhouse conditions as compared to open field condition. Fruit yield was about two times higher inside greenhouse than in the open field due to warm and humid weather inside. Plant growth and yield attributing characters were also found to be higher inside the greenhouse. Jamaludin (2009) reported that tropical greenhouses require active evaporative cooling system such as pad-and-fan to ensure a suitable microclimate for crop production. Excess heat causes indoor temperature becoming hotter than desired resulting in detrimental effects to crop growth and production. Horizontal and vertical profiles of temperature and relative humidity inside the greenhouse were investigated. The study showed that temperature increased from evaporative pad to exhaust fans in a horizontal direction while relative humidity shows inverse pattern from temperature. In the vertical direction, temperature increased, while relative humidity decreased from lower level to the upper level. The inside temperature with growing crops however, was slightly lower than the empty greenhouse.

Variouts echniques for hydroponics

There are different methods of cultivation in hydroponics. The difference in each method is based on the structure set up. Below are some of the systems, which are being used by hydroponic farms around the world.

Nutrient film technique (NFT) systems

In NFT system, the plants are grown in channels known as gullies where the nutrient solution is pumped throughout the reservoir. The plant roots are kept moist by the thin film of nutrient solution. Ideally, the bottom of the roots is exposed to the nutrient solution. It is like a stream that feeds the line with dissolved nutrients. This system delivers a constant flow of nutrients to the plants with a pump, so no timer is required. The nutrient film technique was developed during the late 1960s by Dr. Allan Cooper at the Glasshouse Crops Research Institute in Littlehampton, England. (Winsor 1979); a number of subsequent refinements have been developed at the same institution (Graves 1983). Plants with large root systems that can effectively reach down into the water can be grown using this technique (Turner 2008). Most NFT channels are fed at a rate of approximately 1 liter per minute. It is crucial that roots are kept moist at all times since those are not in a growing medium. The nutrient solution is mixed in a primary reservoir, cycled through the channels and sent back to the reservoir. NFT is suitable for lettuce, tomatoes, leafy crops, herbs, onions, and more of short-term crops. Larger NFT channels are used for long-term crops such as tomatoes and cucumbers in many locations around the world. One another advantage of this technique is that with no growing medium and no soil, the crop grows clean, and no washing is required, farmers can simply have yields (Ali, Noor, and Yahya 2013; Nederhoff and Stanghellini 2010).

Ebb and flow/flood and drain systems

In the Ebb and Flow (also known as flood, and drain) process of hydroponics, a growing area is filled with flow of nutrients for 5 to 10 minutes and then the solution is drained away. The nutrient mixture is stored in a reservoir. Ebb and Flow is used commonly used in hobby systems and not usually in commercial production. In this system, the plant roots are usually grown in a medium of perlite, rockwool, or enlarged clay pebbles.

Drip systems

The drip system which is often used in spot hydroponic facilities is used to grow long-term crops like cucumbers, tomatoes, peppers, onions etc. Drip emitters are used to deliver the nutrient solutions to plants. These timed emitters are scheduled to run for approximately 10 minutes every hour depending on the stage of development of the plant and the amount of light available. Growing media are flushed by drip cycle and provides the fresh nutrients, water and oxygen to the plants. Soil is not required because plants get all that is needed from the system. In drip irrigation hydroponic system, a timer delivers the nutrient solution through the base of each plant through drippers. Continuous drip systems can be recovery or non-recovery, meaning that the used nutrient solution can either be returned to the reservoir or run off as waste. Recovery systems are more cost effective because they use the nutrient solution more effectively, but non-recovery systems require less maintenance because the pH balance and nutrient strength remains constant with fresh solution that is supplied.

Deep flow technique (DFT)-pipe system

As the name implies, more than 2-3 cm deep nutrient solution flows through 10 cm diameter PVC pipes to which plastic net pots with plants are fitted. The plastic pots contain planting materials and their bottoms touch the nutrient solution that flows in the pipes. The PVC pipes may be arranged in one plane or in zig zag shape depending on the types of crops grown. The zig zag system utilizes the space efficiently but suitable for low growing crops. The single plane system is suitable for either tall or short crops. Plants are established in plastic net pots and fixed to the holes made in the PVC pipes. Old coir dust or carbonized rice husk or mixture of both may be used as planting material to fill the net pots. A small piece of net is placed as a lining in the net pots to prevent the planting material from falling into the nutrient solution. Small plastic cups with holes on the sides and bottom may be used instead of net pots. When the recycled solution falls into the stock tank, the nutrient solution gets aerated. The PVC pipes must have a slope with drop of 1 cm in 30-40 cm to facilitate the flow of nutrient solution. This system can be established in the open space or in protected structures as part of CEA. Root Dipping Technique, Capillary Action Technique, Trench or Trough Technique, Pot Technique, Deep Water Culture (DWC) and Surface Watering Technique are the other hydroponic techniques

The floating raft systems

In 1976, a method for growing a number of heads of lettuce or other leafy vegetables on a floating raft of expanded plastic was developed independently by Jensen (Jensen and Collins 1985) in Arizona. Large-scale production facilities are now common and are quite popular in Japan. In the Caribbean, lettuce production has been made possible by combining this system of hydroponics with cooling the nutrient solution, which stops the bolting of lettuce. The floating systems utilize the floating-raft or mat system, in which Styrofoam rafts with holes drilled in them are floated on nutrient-rich water (Sweat, Tyson, and Hochmuth 2003). This system works well with short season, shallow-rooted crops – such as lettuce, basil, and watercress, which grow well under high-moisture conditions in the root zone. This system is also called dynamic root floating techniques (DRFT). The main advantage of the DRFT is that it can maintain the temperature of the nutrient solution. Since oxygen is less soluble in warm water, the DRFT is well-suited for hydroponic farming in tropical and subtropical climates such as those found in Thailand (Kao 1991).

Aquaponics systems

In aquaponics, i.e., fish farming is combined with hydroponic production. The nutrient-rich wastewater from the fish tanks is given through plant grow beds. The key to aquaponics is the endowment of a healthy bacteria population. The ammonia is converted to nitrate by beneficial bacteria that naturally occur in soil, air and water which the plants readily uptake. It is presumed that by consuming the nitrate and other nutrients in an aquaponic system, the plants help to purify the water which shows synergies (Tani, Fukushima, and Uchikado 2012).

Aeroponics systems

Aeroponics is a newer and more high-tech method of hydroponic growing. The plants are suspended with roots in the air and the nutrients and moisture are supplied in the form of a mist. A timer ensures that the pump delivers a new spray of mist (water) every few minutes. Like the nutrient film technique, it is imperative that the pump is always functioning correctly, because even a brief interruption can cause the roots to dry out. This technique is generally suitable for low leafy vegetables like lettuce, and spinach. Root Mist Technique (RMT) and Fog Feed Technique (FFT) are the two important Aeroponic Hydroponic Techniques in use (Alimuddin et al. 2018). Aeroponic techniques have been given special attention from NASA since a mist is easier to handle than a liquid in a zero-gravity environment (Cooper 1976). The first commercially available aeroponic apparatus was manufactured and marketed by GTI in 1983. It was known then as the “Genesis Machine”. The Genesis machine was marketed as “Genesis rooting system”.

Design of this system includes an A-frame with boards on each side, and plant plugs are set on each side and a mister between the boards (Chen et al. 2015). A round, large diameter poly vinyl chloride (PVC) pipe is set vertically with plant plugs. Although it is a unique way of growing and it is not a common means of spot production.

Computers, electronics, and automation in hydroponic farming

The rapid evolution of electronics, coupled with the increasing expansion of the market, has enabled access to state-of-the-art technology and tools that in the past were available only in well-equipped laboratories and research centers. Agricultural engineering, in general, has benefited from this technological advance, be it from the development of new equipment, or in adapting those already available to other sectors of production, to be used in agriculture (Queiroz 2007). Diego Domingues et al. described the development of an automated system, capable to control online via software and webcam, pH and conductivity, even with the great variation of the temperature in greenhouse along 24 h, during whole cycle of lettuce cultivation. Also, he explained, how the system automatically fixes the pH and concentration of nutrients of solution that irrigates the hydroponic lettuce, by opening and closing of solenoid valves, by delivering solutions acids, basics and nutrients.

To evaluate the efficiency of the proposed system, agronomic characteristics such as quantities of fresh and dry matter in the aerial part, dry matter in the root, total number of leaves, and number of leaves larger than ten centimeters, as well as, chemical parameters, like levels of macro and micronutrients, were analyzed to attest the nutritional quality of lettuce produced, compared with conventional soil grown, considered as referential. It promised an addition of nutrients more "intelligent", reflecting in better productivity, preserving the nutritional quality of the product. Xavier Rius-Ruiz et al. (2014) reported for the first time a new computer-operated analytical platform which can be used readily for the determination of essential nutrients in hydroponic growing systems. The liquid-handling system uses inexpensive components (i.e., peristaltic pump and solenoid valves), which are discreetly computer operated to automatically condition, calibrate and clean a multi-probe of solid-contact ion-selective electrodes (ISEs). These ISEs, which are based on carbon nanotubes, offer high portability, robustness and easy maintenance and storage. With this new computer operated analytical platform they performed automatic measurements of K^+, Ca^{2+}, $NO_3{}^-$ and Cl^- during tomato plants growth in order to assure optimal nutritional uptake and tomato production. Antonio, Zolnier, and Lopes (2014) developed an automatic control system for real time preparation and application of nutrient solution for soilless tomato production. The control strategy was based on transpiration estimates by the Penman–Monteith model and on leachate concentration by measurements of electrical conductivity.

The performance of the fertigation system was evaluated during tomato cultivation in sand substrate under greenhouse conditions. The commercial crop yield was 4.74 kg m^{-2}, and the average total soluble solids of tomato fruits was 4.50 Brix. Water use efficiency for tomato crop cultivated with the developed control system was 17.94 kg m^{-3}. To produce 1 kg of tomato fruits, 44.42 liter of nutrient solution was necessary. The proposed system was efficient in controlling the prepared nutrient solution concentration, minimizing environmental problems related to effluent disposal and contributing to the economy of fertilizer and water resources.

Mathematical modeling in soilless culture

Under precision irrigation applications, water and associated solute movement will vary spatially within the root zone. The interpretation and subsequent modeling of soil water dynamics and nutrient uptake in presence of active plant roots remains a challenge. Despite many simplifying assumptions in their development, analytical models offer simple and easy means for prediction of soil water and nutrient dynamics that could be generalized readily for development of design and management guidelines. Son (1996) developed an experimental model and conducted neural network based electrical conductivity estimation in soilless culture system. In this study, the experimental EC prediction equation, an extended form of the Robinson and Stroke's theoretical equation only available for a binary electrolyte, was developed for predicting the EC of the nutrient solution containing many kinds of inorganic compounds. And the multilayer perceptron consisting of three layers with the back-propagation learning algorithm was developed for EC prediction. It consists of nine variables in the input layer for the concentrations of seven macro elements, Na + and Cl, and one variable in the output layer for the EC of nutrient solution. The predicted ECs by experimental model as well as neural networks for the nutrient solution were compared to the measured ones and showed good agreements. Mmolawa and Or (2000) reported that infiltration and subsequent distribution of water and solutes under cropped conditions is strongly dependent on the irrigation method, soil type, crop root distribution, and uptake patterns and rates of water and solutes. Fertigation with poor quality water can lead to accumulation of salts in the root zone to toxic levels, potentially causing deterioration of soil hydraulic and physical properties. The high frequency of application under drip irrigation enables maintenance of salts at tolerable levels within the rooting zone. Modeling of root uptake of water and solutes is commonly based on incorporating spatial root distribution and root length or density.

Marfa et al. (2000) studied on the water consumption of a closed soilless culture of gerbera and the usefulness of models to estimate evapotranspiration. Gerbera plants were grown in grow bags and the leachates were continuously recycled. Full crop evapotranspiration was measured daily during the growing period. Simultaneously, the evapotranspiration rate was measured at short time intervals by continuously weighing plants placed on an electronic balance. Solar radiation (G), relative humidity and dry bulb air temperature were measured at short-time scales; leaf stomata resistance and leaf area index (LAI) were measured periodically. The evapotranspiration rate was also estimated ($ET_{c,i}$) using the Penman-Monteith equation and compared with the measured values at short-time scales ($ET_{m,i}$) and at the daily scale ($ET_{m,d}$). Results obtained using the Penman-Monteith equation to estimate the ET at short time scales gives an acceptable accuracy for the management of watering a closed soilless culture of gerbera in Mediterranean conditions. The accuracy obtained using this equation is higher than that obtained from the multivariate regression from G and VPD. Ondrasek et al. (2007) conducted a study on comparison of transpiration models in Tomato Soilless Culture. A two-year greenhouse study was performed to determine the possibility of estimating the transpiration rate in hydroponically grown tomato on the basis of climate parameters. Transpiration rate, determined by the water balance method on different substrates, was compared to the transpiration rate calculated using the Penman-Monteith equation. Regression analysis of the comparison of two different approaches to water consumption determination confirmed that the transpiration rate of greenhouse grown tomato for the studied area can be estimated with high accuracy ($R2 > 0.95$). Silberbush and Ben-Asher (2001) developed a theoretical model to simulate nutrient uptake by plants grown in soilless cultures with recycled solutions. The model accounts for salinity accumulation with time and plant growth, and its effects on uptake of the different nutrients by means of interaction with Na and Cl ions. The sink term occurs due to uptake by a growing root system. Influx as a function of the ion concentration is according to Michaelis–Menten active mechanisms for K^+, NO_3^--N, NH_4^+-N, PO_4-P, Ca^{2+}, Mg^{2+} and SO_4^{2-}, whose influx parameters are affected by Na and Cl^-, but not with time (age). Sodium influx is passive above a critical concentration. Sum of cations–anions concentrations is balanced by Cl^- to maintain electro-neutrality of the growth solution. Salinity (by means of Na concentration) suppresses root and leaf growth, which further effect uptake and transpiration. The model accounts for instantaneous transpiration losses, during daytime only and its effect on uptake of nutrients and plant development due to salt accumulation. The model was tested against NO_3^- and K^+ uptake by plants associated with cumulative transpiration and with different NaCl salinity levels. Deviations from observed $K+$ uptake should be attributed to the salinity tolerance of the plants. The model indicated that nutrient depletion and salinity buildup might be completely different with fully grown-up plants (that do not grow) and plants that grow with time. Depletion of different nutrients are according to their initial concentration and plant uptake rate, but also affected by their interactions with Na and Cl ions. Varlagas et al. conducted an investigation to simulate the uptake concentrations (weights of ion per volume of water absorbed) of Na^+ and Cl^- in hydroponic tomato crops as a function of the NaCl concentration in the root zone.

An empirical model was calibrated and validated, which can be incorporated into online operating decision support systems aimed at optimizing the nutrient supply and minimizing the discharge of drainage solution in tomato crops grown in closed-cycle hydroponic systems. The model could successfully predict the uptake concentration of Na^+, but Cl^- could not be simulated by this model at external Cl^- concentrations lower than 10 mol m^{-3}. The results indicate that Na^+ is excluded actively and effectively by the tested tomato cultivar even at low external Na^+ concentrations, while Cl^- is readily taken up at low concentrations, particularly during the initial growing stages. Due to the efficient exclusion of Na^+ by tomato, the Na^+ concentration in the root environment increased rapidly to extremely high levels even when the Na^+ concentration in the irrigation water was relatively low. These results indicate that tomato genotypes characterized by high salt-exclusion efficiency, require irrigation water with a very low NaCl concentration, if they are grown in closed hydroponic systems and the drainage water is not flushed periodically. To maintain Na + at levels lower than 19 mol m^{-3} in the root zone of the tomato hybrid 'Formula' in closed hydroponics, a maximum acceptable Na + concentration of 0.53 mol m^{-3} was estimated for the irrigation water. The model 'WATERSTREAMS' was developed by Voogt et al. (2012) to estimate the total water demand and waste water flows from greenhouse crops and to optimize between options for water sources, concerning Na accumulation and nutrient emission. It describes all water flows in a greenhouse crop and the growing system.

At the same time the Na concentrations in the input flows as well as the uptake are calculated, and if Na accumulates beyond a threshold value, a discharge event is programmed. The model calculations can be used to determine the total water demand from individual crops to clusters of greenhouses, as well as to optimize the size of rainwater collection tanks or the required capacity of additional water sources, using actual, historical or forecasted meteorological data. It also gives insight in the emission quantity.

Advantages

In hydroponics some plants can be grown closer together than in the field because roots are directly fed; thereby increasing the yield per unit area and multiple cropping can be practiced. Plants grow faster because they get all the nutrients they need in proper amounts and proportions.

Less water and space

Hydroponic uses less than 1/10th to 1/5th of the water used in soil cultivation (Saaid et al. 2013). The limited space requirement increases the advantage of hydroponic because it can be installed in terraces, balconies and courtyards. Therefore, it gives a great opportunity for the production of fresh crops in urban areas too also as it also maximizes space saving so that it is possible to store in areas that are normally unusable (Devvrat 2018; Morgan and Paugh 2004). Hydroponic gardens can produce the same yield as soil gardens in about 1/5 of the space (Sardare and Admane 2013). This is a major space savings which makes it possible for a civilization to produce more for people by using less space.

Optimum control

The achievement of maximum yield by the supply of sufficient quality of nutrients and optimum microclimatic conditions (More complete control of nutrient content, pH and growing environment) are the main objectives of hydroponics (Aqee,2015). It can be used in places where in-ground agriculture or gardening is not possible (for example, dry desert areas or cold climate regions). Faster growth due to more available oxygen in root area.

Pesticide free

Hydroponic does not need any fertile soil for production process. In addition, since soil is excluded from the production process, so there will not be any problem related to soil borne diseases, pests and weeds. By the exclusion of such problems, there will not be any use of harmful plant protection chemicals, so the yield will be fresh and healthy.

Disadvantages

Initial and operational costs are higher than soil culture. Skill and knowledge are needed to operate properly. Some diseases like Fusarium and Verticillium can spread quickly through the system.

Hydroponics vs traditional farming

Soil is usually the most available growing medium for plants. It provides anchorage, nutrients, air, water, etc. for successful plant growth (Ellis et al. 1974). However, soil does pose serious limitations for plant growth too, at times. Presence of disease-causing organisms and nematodes, unsuitable soil reaction, unfavorable soil compaction, poor drainage, degradation due to erosion etc. are some of them. In addition, conventional crop growing in soil (Open Field Agriculture) is somewhat difficult as it involves large space, lots of labor and large volumes of water. Moreover, some places like metropolitan areas, soil is not available for crop growing at all, or in some areas, we find scarcity of fertile cultivable arable lands due to their unfavorable geographical or topographical conditions. Of late, another serious problem experienced since is the difficulty to hire labor for conventional open field agriculture. Under such circumstances, soilless culture can be introduced successfully (Beibel 1960). Hydroponic farming offers many advantages when compared to conventional farming. One of the main advantages is that crops can be grown in places with barren or contaminated land. Hydroponically grown plants are also more resistant to water with a high salt content. Another advantage includes not having insects, animals, and diseases such as fungi already present in the growing medium. Labor intensive work such as tilling, cultivating, fumigation, and watering is not required for hydroponic farming. If the system is automated using pumps or even computers, labor costs decrease dramatically (Jones 1997). The main disadvantage of hydroponic systems is that the initial startup cost, which is rather high. Also, diseases in hydroponic systems can spread very quickly to all beds sharing the same nutrient tank. So daily inspection is required (Resh 1997). In hydroponics, plants get perfectly balanced diet (Linden et al. 2000). Hydroponics is regarded as one of the most advanced growing techniques not only for environmental protection but also for high efficiency of vegetable production. Since plant growth in hydroponics is generally faster than in the conventional soil culture, more intensive and successive cropping production is carried out all year round (Savvas 2003).

Hydroponics is a method of growing plants without soil, using a continuous water flow containing mineral nutrients. This system is water-, energy-, space-, and cost-efficient. It saves 5 to 10 times more water due to the recycling system, and produces up to 10- 15 times more food than traditional soil-based methods (Winterborne 2005). Soilless growing media are easier to handle and may provide a better growing environment compared to soil (Bilderback et al. 2005; Mastouri, Hassandokht, and Padasht 2005). Soilless culture is considered one of the main components of sustainable protected horticulture. In fact, the application of closed growing systems, where the drainage water is captured and reused after nutrient replenishment, can reduce the consumption of water and fertilizers and the environmental pollution that are generally associated to over-irrigation (Pardossi et al. 2006). The greenhouse systems that use hydroponics are considered to be superior to field production systems in terms of water and nutrient use efficiencies (Bradley and Marulanda, 2001). A greenhouse cucumber crop in Florida (USA) required one third of the amount of water, 28 per cent less nitrogen and 23 percent less potassium per kilogram of fruit compared with a field grown cucumber crop (Jovicich et al. 2007). Melgarejo et al. (2007) reported that soil-free cultivation may allow irrigated farms to boost their fig productions from 4500 kg/ha-year up to 81,000 kg/ha-year; that is an 18- fold yield increase compared to traditional farming. A 90 percent water reduction was achieved by applying this growing technique. Furthermore, fertilizers and pesticide applications, as well as farming costs (hand labor) may be reduced by growing the appropriate fig cultivars. Moreover, the highest fig market demand could be met by scheduling harvest to provide quality fruit all year round. Hydroponic systems are very efficient. In general, hydroponic plants use only one-tenth of the amount of water used by plants grown in soil because in traditional farming a majority of the water passes through the root layer quickly. The nutrient solution, required for hydroponic farming, needs only 25 percent of the amount of essential elements found in soil based fertilizers. Since plants do not have to compete for surrounding soil space for nutrient reserves, more plants can be grown using less space in a hydroponic system. Spacing is limited only by the amount of available light. Plants also grow much faster and bigger in hydroponic systems. Therefore, hydroponic systems have higher yields per unit area when compared to traditional farming (Turner 2008). Some types of hydroponic systems also require a continuous and reliable power supply, as plant roots can dry out quickly if pumps or sprayers fail. Hydroponic systems require a lot of scientific and technical knowledge; however, the process is actually very simple and pre-mixed nutrient solutions can be purchased. In addition, higher yields and less intensive labor can make hydroponic systems very marketable (Turner 2008). Maboko, Du Plooy, and Bertling (2009) indicated that plants in the soilless system developed faster with higher total yield compared with in-soil cultivation. The average marketable yield using soilless cultivation was 92.1 per cent, while in-soil cultivation was only 77.0 per cent. Results indicate that soilless cultivation can improve yield and quality, with cultivar selection playing an important role when utilizing this production system. In general, soilless crops are more convenient than ordinary crops when it is necessary to operate in difficult psuedoclimatic conditions or in the presence of very valuable species that are difficult to cultivate, or during the multiplication and reproduction phase. For ornamental crops and cut flowers, soilless cultivation in a protected environment ensures a more constant and higher quality production, and favors production planning, the latter being of fundamental importance in this sector (Rosario et al. 2013).

Hydroponics in India

In India, Hydroponics was introduced in year 1946 by an English scientist, W. J. Shalto Duglas and he established a laboratory in Kalimpong area, West Bengal. He has also written a book on Hydroponics, named as Hydroponics-The Bengal System. That work stopped when he returned to England. In India, the actual hydroponic farming was launched in 2009 as “Pet Bharo project” executed by The Institute of Simplified Hydroponics, a division of optimus inter weave, Australia, based in Bangalore. The chief visionary of the project is Mr. C.V. Prakash. The project aims to make low cost and easy to learn hydroponics or soilless cultivation methods accessible to rural and urban growers of vegetables, fruits and herbs in India. They conduct training; provide consultancy service and materials for establishing hydroponics. They have trained many faculties within and from other agriculture and horticulture institutions in India including senior experts and professionals.

Below are four startups in India in which innovating agriculture techniques have been implemented and are leading the way in indoor farming.

Future farms

Chennai-based future farms developed effective and accessible farming kits to facilitate hydroponic system that preserves environment while growing cleaner, fresher and healthier produce. It focuses on being environment friendly through rooftop farming and precision agriculture. The company develops indigenous systems and solutions, made from premium, food grade materials that are efficient and affordable.

Letcetra agritech

Letcetra Agritech is Goa's first, indoor hydroponic farm, growing good quality, pesticide-free vegetables. The farm in Goa's Mapusa is an unused shed and currently produces over 1.5 to 2 tons of leafy vegetables like various varieties of lettuce and herbs in its 150 sq. meter area. Ajay Naik, a software engineer-turned-hydroponic farmer, founded this startup.

Bit-Mantis innovations

Bengaluru-based IoT and data analytics startup Bit-Mantis Innovation with its IoT solution Green-Sage enables individuals and commercial growers to grow fresh herbs throughout the year. The Green-Sage is a micro-edition kit that uses hydroponic methods for efficient use of water and nutrients. It is equipped with two trays to grow microgreens at one's own convenience.

Junga fresh N green

Agri-tech startup Junga Fresh N Green has joined hands with Infra Co Asia Development Pte. Ltd. (IAD) to develop hydroponic farming methods in India. The project started with the development of a 9.3 hectare hydroponic-based agricultural facility at Junga in Himachal Pradesh's Shimla district. Junga Fresh N Green is a joint venture with a leading Netherlands-based agricultural technology company – Westlandse Project Combinatie BV (WPC) — to set up high-technology farms in India. The goal is to create a hydroponic model cultivating farm fresh vegetables that have a predictable quality, having little or no pesticides and unaffected by weather or soil conditions (Anon. 2016).

Besides the above-mentioned projects, many other persons are working in the field of automated hydroponic. Indian government is also funding such concepts.

Hydroponic in foreign countries

As the idea of a hydroponic control system for an indoor system became the topic of this research, there are other systems too, which constitute good features. This section covers various projects or products those are somehow related to the developed research. Some of these systems were used as an aid for the developed system by providing information that was not originally thought about. While others helped in the issues related to the design, development, and implementation process. There are many different hydroponic controllers in the market and all the features so far created in those are a way for people to grow plants without doing everything manually. With the consideration of all the systems, the developed hydroponic system utilizes features from each of these systems to maximize the benefits of what has already been done. During the 1960s and 70 s, commercial hydroponics farms were developed in Abu Dhabi, Arizona, Belgium, California, Denmark, German, Holland, Iran, Italy, Japan, Russian Federation and other countries. During the 1980s, many automated and computerized hydroponics farms were established around the world. Home hydroponics kits became popular during the 1990s.

Hyduino

Hyduino is hydroponic system was made in Japan that has a lot of documentation on the web. Its system uses the Atmega 2560 microcontroller to control its various systems. This system was created to control its lights and the pH levels using peristaltic pumps similar to developed system. A light sensor has been implemented to control its lights and a liquid crystal display (LCD) touch screen to monitor the pH, water level, and temperature value. This system also uses relays to control the different systems from the pins of the Atmega microcontroller unit. While this system is similar to developed system, but this design does not include a total dissolved solids sensor to control the quantity of nutrients. Another way to improve this system is with wireless fidelity (Wi-Fi) and the internet. The data while being read on LCD screen will also be uploaded to an online database through a Wi-Fi module connected to the internet. This will allow the user to monitor the hydroponic system from any location with internet access.

Leaf-Alone hydroponic system

Leaf-Alone Hydroponic System is a system that was designed in 2014 by Horticulture Research Laboratory in Malaysia (Gonzalez, *et al.*,2012). This system was designed to run on solar and battery power to conserve energy. While this system was eco-friendly, the cost of the solar system was exorbitant. This system used the Atmega 328 as the microcontroller to control all their subsystems. The WiFi system to communicate real time data to the web has been implemented where it could be read in graphs or charts. In this system, user collects data from pH sensor, electrical conductivity sensor, water and temperature sensors. One aspect of the system, which is not included, is the use of a camera to remotely monitor the system by visually inspecting the progress of the system. One way to improve this system is the implementation of LCD screen in the system. This will give the user visual implementation that the system is working.

Autopilot greenhouse master controller (GMC)

This system was developed in Indonesia in 2015 to precisely control temperature, humidity, and CO_2 levels in the growing system (Krauss et al. 2006) This system is designed to be user friendly with controls directly on the front of the unit to control the various functions. In addition, there are lights (easy to read error warning) on the unit to warn when something in the system is not right. Instead of this system sending its data to an online database, it has a built-in data logger to store the sensor data. This might be convenient for the systems that are off the grid and have no way to access the internet. In addition, this system has been designed to resist electro-magnetic interference (EMI) from subsystems such as relays and light ballasts. While this system is a simple plug n play type system, it lacks the needed sensors used for the measurement of pH and TDS (Krauss et al. 2006).

National institute of water and atmospheric research New Zealand

(NIWA) hydroponic system, which is made to allow the everyday consumer to be able to grow in home with the simplicity of using a mobile application on a smart-phone (Sabat, Kaniszewski, and Dysko 2014). All the care that the plants need comes directly from interactions through the application on a mobile device. The application can control the irrigation, heating system, lighting, ventilation, and climate control. Through this android application, one can monitor the growth of the plants and adjust when necessary. This application also allows connection with other NIWA system growers to broaden the understanding on what is needed for good plant growth. This system is designed to be an all in one system which runs quietly, efficiently with minimum maintenance.

Cloudponics

This system is similar to NIWA system. It uses a remote application on farmers' smart device to monitor and control the system from anywhere in the world with their Cloudponics, which has been developed in California in 2012. This system uses peristaltic pumps to control the pH, nutrients, and fresh water needs (Santos et al. 2016). With the peace of mind of the plants getting the needed requirements daily, the user is free not to worry when away for an extended period. This system monitors the air temperature, humidity, and light intensity that the plants are receiving. If required, it can control fans and humidity to bring within the proper specifications of the plants. Three separate peristaltic pumps can be custom designed to inject custom designed nutrients to the plants depending on the stage of the plants at a touch of a button. By experimenting with three different types of nutrients and the mix needed for plants, user can see what works and what doesn't and are able to change what a plant needs during the different growing cycles.

Growtronix

Growtronix was developed in Canada, has a clean and professional looking system and its focus is on automation. The hydroponic controllers on the site are very clean looking and what looked appealing with their system were the following components (Wallihan, Sharpless, and Printy2007). A TDS sensor installed in it will read the salinity in the water for the user to interface and know when the system needs to have more nutrients added. This system also features a pH system to measure the pH of the water. If the solution the plants are growing in does not have the correct pH the plants will not be able to take in the proper nutrients. The pH sensor is equally necessary and is a must have feature for a grower who wants to automate the hydroponic system. To go along with these sensors, a controller is designed to be able to control the addition of nutrients, pH up, and pH down. With the dosing pump the user can let the controller handle the balance of the growing solution to produce a plentiful yield for the end user. The final product that has been designed of interest is the ability to control a power supply. A huge advantage that this company is offering is the ability for the user to interface with these devices electronically. The system interfaces with the user via computer or an application. For the grower to be able to get data in their hands when need. With the electronic system, the user can control the set points of the pH, total dissolved content (TDS), and lights depending on the needs of the plants.

Agrowtek

Agrowtek has designed a complete hydroponic control system for a grower to automate the growing operation (Ho 2001). The system has the typical pH sensor, TDS sensor, pump control, and power-controlled timers. However, the addition of an LCD screen on the wall mount controller is very interesting. It is one thing to have the information available on a computer or phone, but to have an LCD screen adds the ability to visualize and control the system in the event the user is in the grow room and does not have their electronic device on hand. Another advantage of having an LCD screen is to be able to adjust the system if there are any issues with internet connectivity. Another interesting feature of this system is the ability to control the climate. Temperature sensors are also added which can control fans or an air-conditioning system. The down side of the system is the cost. This complete system is more geared to a large growing operation such as a nursery setting. The design is focused on the average person wants to grow inside home to know the quality of the food which are eating so from this system the one feature that will be utilized is the LCD display.

Huertomato

The Huertomato hydroponic controller was the final system that under consideration which was developed in Japan (Hyuk and Ikeda 2004). The ability to control the system from one interface is a feature that makes this system different from others. The Huertomato controller does the same functions as the previous two systems such as monitor pH, TDS, humidity, and temperature. However, an interesting feature that makes this system stand out is a light sensor.

The Huertomato system utilizes a light sensor to measure light intensity. The microcontroller monitors the system and will monitor ambient light by measuring light intensity with a sensor. When the light intensity drops below a set value, the microcontroller controls the ability to water the garden at that time. The utilization of a light sensor is a great feature that will be considered for the developed system.

Hydroponics in space

Hydroponics for space, its application in purification of water, maintaining a balance between oxygen (O_2) and carbon dioxide (CO_2) in space stations and providing food for astronauts is being intensively researched (Knight1989; Schwartzkopf 2000; Brooks 2000). Hydroponics intended to take place on Mars using LED lighting to grown in different color spectrums with much less heat (Budenheim, 1995). Hydroponic growth is of high interest for long-term space programs, as fresh food is highly beneficial for crew members of long-term manned space missions (Drysdale and Hanford 2002). Growing animals as a food source is not a viable option for space missions, so fresh foods can be prepared only from growing plants. The NASA Advanced Life Support (ALS) Program currently nominates twelve crops for growth and use as foodstuffs in such missions, and tomato is one of them (Drysdale and Hanford 2002). Hydroponics also will be important to the future of the space program. NASA has extensive hydroponics research plans in place, which will benefit current space exploration, as well as future, long-term colonization of Mars or the Moon. As we haven't yet found soil that can support life in space, and the logistics of transporting soil via the space shuttles seems impractical, hydroponics could be key to the future of space exploration. The benefits of hydroponics in space are two-fold: It offers the potential for a larger variety of food, and it provides a biological aspect, called a bio-regenerative life support system. This simply means that as the plants grow, they will absorb carbon dioxide and stale air and provide renewed oxygen through the plant's natural growing process. This is important for long-range habitation of both the space stations and other planets (Van Os, Gieling, and Ruijs 2002).

Why hydroponics is future in India

Nowadays, the traditional farming system does not meet the current and maybe will not meet the future demands of food. Therefore, there is a real need for adapting new farming system that stimulates plants to grow faster. Also due to overuse of pesticides and insecticides the land is getting infertile which diverts the practice toward soilless farming. The water which is being used for agriculture mainly comes from river but with the progress of industrialization, toxic waste is dumped in these rivers. This makes them polluted with heavy metals and other toxins due to which water availability for conventional farming will not be available. Thus, one will have to shift toward hydroponics where 80-90% less water is used.

Conclusion

Hydroponics is an age old method which is getting lime-light again as it is a promising technological solution to the problems faced by current agricultural system. Hydroponics may be used in underdeveloped countries for food production in limited space. It is even feasible to grow hydroponically in areas of poor soil conditions such as deserts. It has many pros but major drawback is its high capital investment and needs clear knowledge as it is a perfect combination of biology, chemistry, physics and mathematics. One of the setbacks here is, that no specification and optimization of nutritional requirements for different crops is done, it is just leafy and fruiting vegetables. Yet the popularity of hydroponics has increased dramatically in a short period of time leading to an increase in experimentation and research in the area of indoor and outdoor hydroponic cultivation. With the help of this technique, the demand and supply gap can be filled providing fresh and better quality also consistency can be maintained.

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