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HYDROPONICS SUSTAINABLE APPROACH OF VEGETABLE PRODUCTION: A REVIEW

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ABSTRACT

Hydroponics is a technique of growing the plants in water with nutrient rich solution. Large number of crops and plants or vegetables can be grown by this system. Hydroponic system is gaining popularity because of high and quality food production with efficient nutrient management. The products grown in this system has higher nutritive content, taste, yield and quality than the traditional based farming. This system is ecofriendly, cost effective and disease free, which is popular throughout world both in developed and the developing countries. Due to increase in global warming, industrialization and urbanization, traditional farming or soil cultivation is facing problems. Unpredictable climatic conditions *viz.*, change in temperature, drought, flood, natural disaster and indiscriminate use of pesticide leads depletion of soil fertility and quality. Various types of hydroponics systems were defined in this review paper, with their advantages, disadvantages, opportunities and challenges. In this system, management EC and pH of nutrient solution are need to handle successfully. Nutrient film technique has been used on large scale, with 70 to 90% savings of water and successful production of leafy as well as other vegetables. Canada, Israel, Netherland, Australia, England, France, Israel and USA are leading countries in hydroponic technique. So, we need to develop cost effective system which is easy to operate, require less labour, lower initial cost and overall setup cost.

Key words : Growing media, Hydroponics, Industrialization, Nutrient solution.

Introduction

Hydroponics is a technique of growing plants in the nutrient solutions, which may or may not include an inert medium like gravel, vermiculite, rockwool, peat moss, sawdust, coir dust or coconut fibre for structural support. Hydroponics term was derived from the two Greek words ‘hydro’ means water and ‘ponos’ means labour which means water work. In the early 1930s, the word was coined by Professor William Gericke. In India, hydroponics was introduced in 1946 by the English scientist W.J. Shalto Duglas. He established a laboratory in the Kalimpong region of West Bengal and authored a book titled *Hydroponics: The Bengal System* (Pant *et al.*, 2018). Hydroponics also defined as a method of growing plants without soil, with their roots submerged in a nutrient solution. Similarly, Savaas (2003) described hydroponics as the cultivation of plants without the use of soil. Control on the amount of water, nutrients and light requirements of various crops is operated automatically in most of hydroponics system (Resh, 2013). Soilless cultivation (hydroponics, aquaponics and aeroponics) are done along with substrate culture. These hydroponic systems have quickly gained popularity due to their efficient management of resources and crop production (Hussain *et al.*, 2014).

To sustainably feed the increasing global population, new food-growing systems need to be established. Currently, soilless cultivation can be effectively initiated and seen as a good alternative for growing nutritious food plants, crops and vegetables. Soilless farming is a practical method for producing healthy edible plants that can be properly implemented and assessed (Butler and Oebker, 2006). Most hydroponic systems function automatically to regulate the water, nutrients and light duration according to the needs of various plants. Various crops can be cultivated through hydroponics, such as leafy vegetables, tomatoes, cucumbers, peppers, strawberries, and others. Biggest market of hydroponics is in Europe. Israel, Netherland, Spain and Asia are leading countries of hydroponics (Prakash *et al.*, 2020). The increasing population, urbanization, and industrialization are causing a continuous decline in arable land. Traditional crop production methods are encountering numerous challenges due to unusual climate conditions. Therefore, innovative and modern techniques for producing enough food must be developed to sustainably feed the world's expanding population. Changing the growing medium could serve as an alternative strategy for sustainable crop production and the conservation of rapidly depleting land and water resources.

Hydroponic systems and their operations

The techniques used in hydroponic systems include the wick method, ebb and flow method, deep water culture method and drip method.

Types of circulating system in hydroponics

It is also known as the Liquid Hydroponics approach. Solution culture involves suspending plant roots in a nutrient solution. The hydroponic system has been classified into two groups they are: open system, closed system. In open hydroponic systems, the nutrient solution in touch with the roots is only used once. This indicates that nutrient solutions are not circulated or recycled. This technique eliminates the possibility of plant infection due to constant fertilizer solution changes. Whereas, in closed system, nutrient solution used by plants is collected and return back to the reservoir on a periodic basis. This implies the nutritional solution will be recycled periodically. This approach involves growing plants in a liquid media or solid substrate, such as sawdust, rice husk, charcoal, sand, gravel, or pumice. Water and nutrients are checked and recycled regularly. The major disadvantage of this technique is its dependence on power (Lee and Lee, 2015).

Wick method

This is the most basic hydroponic system, which doesn't require electricity, pumps or aerators (George and George, 2016). In this setup, plants are placed in an absorbent growing medium such as perlite or cocopeat, with a nylon wick extending from the plant roots into a reservoir of nutrient solution (Fig. 1). Water or nutrient solution is delivered to the plants through capillary action. Wick system is highly suitable for light feeder crops *viz.,* herbs, spices and small plants, but not suitable for heavy feeder crops that require large amount of water.

Ebb and flow method

This system operates on the flood and drain principle (Fig. 1). Here, a nutrient solution is pumped from a reservoir into the growing medium, temporarily flooding it, and then the solution drains back into the reservoir. This drainage allows air to enter the rooting area, providing a source of oxygen. Plants can absorb water and nutrients from the moist medium. However, this system results in fluctuating conditions for the roots, which may not be optimal for plant growth and development, though overall plant performance tends to be satisfactory with this hydroponic method. Additionally, issues such as root rot, algae and mould are common in this system, so a modified system with a filtration unit is often required (Nielsen *et al.,* 2006).

Deep water culture (DWC)

In this method, plant roots are suspended in nutrient-rich water, with air supplied directly to them using an air stone. A well-known example of this approach is the hydroponics bucket system. It's essential to regularly and carefully monitor oxygen levels, nutrient concentrations, salinity and pH, as there's a risk of rapid algae and mould growth in the reservoir (Domingues *et al*., 2012). Vegetables such as cucumbers and tomatoes can be grown very successfully using this method (Fig. 1).

Drip system

This technique separates the nutrient solution in a reservoir, while the plants grow on a soilless media. The reservoir contains water or nutrition solution. Raphael and Colla (2005) suggested, using a pump to deliver an adequate percentage of water to individual plant roots. Drip systems slowly feed nutrients through nozzles, allowing excess solutions to be collected and recirculated or drained (Fig. 1). This technique allows for simultaneous growth of multiple types of plants.

Nutrient film technique

Dr. Allen Cooper developed NFT in the mid-1960s in England to improve ebb and flow systems. The nutrient film technique (NFT), like aeroponics, is the most common hydroponic system. According to Domingos *et al.* (2012), this method involves continuously pumping nutritional solution in the channel which is slightly tilted at an angle. After that nutrient solution again return back to the reservoir from the lower end of the channel. This method is recirculating, but unlike DWC, the plants' roots are not fully submerged, hence the name NFT (Fig. 1).

Advantage of hydroponics

There are various advantages of growing plants in hydroponic system over conventional system. 1)

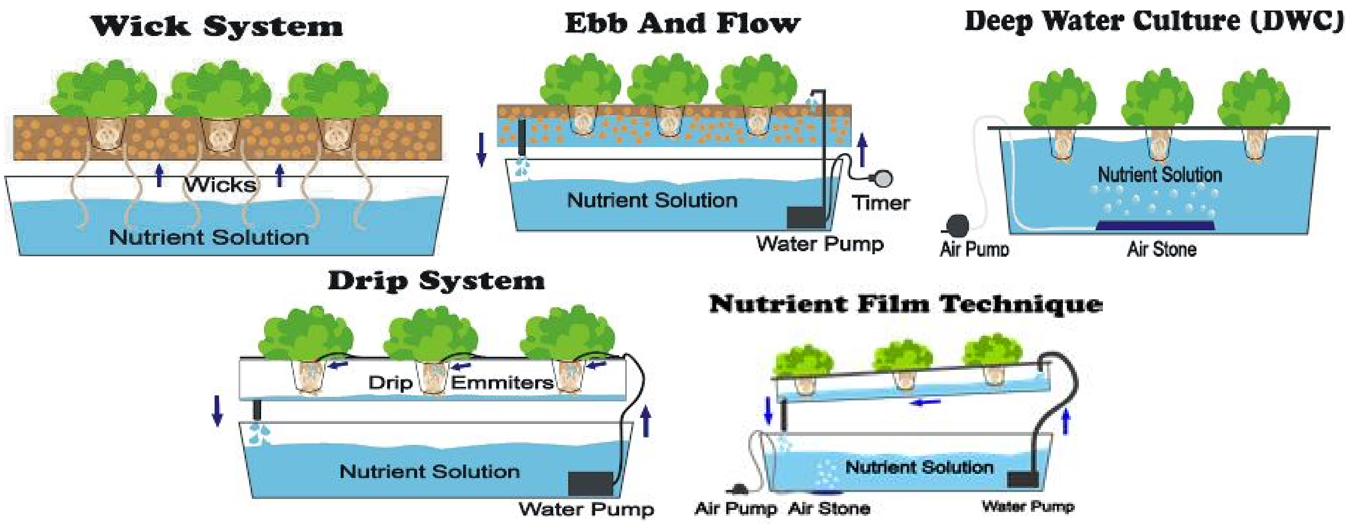

Fig. 1 : Different structures of hydroponic system.

Hydroponics system require less space for crop production as compare to traditional growing method (Barbosa *et al*., 2015). 2) Crops can be cultivated at place where there is no suitable soil available for crop production or where soil is prone to diseases (Barbosa *et al.*, 2015). 3) Requirement of the labour for intercultural operations like tilling, weeding, irrigation and other cultural practices are eliminated (Jovicich *et al.*, 2003). 4). Efficiency of utilization of water and nutrient is more in this system than conventional system. This also leads to reduction in the pollution of water and land by minimum leaching of the valuable chemicals (Adler *et al.*, 2000). 5) Soil borne diseases can be eliminated by growing the plants in this system (Tyson *et al*., 2015). 6) Main advantage of this system is to conserve the water and also help to avoid waterlogging conditions. 20% less water required in hydroponics than traditional farming methods to produce the same amount of food, saving significant resources (Naresh *et al*., 2024). 7) This system provides complete control over the entire environment (i.e. timely nutrient feeding, irrigation and root environment) and different greenhouse type operations, the light, temperature, humidity and composition of the air can be manipulated very easily (Baddadi *et al*., 2019). 8) Crops which are grown hydroponically are easier to harvest than conventional system practices (Goddek *et al*., 2015). 9) Hydroponically grown crops are more tasty and healthier for consumption (Naresh *et al*., 2024). 10) Hydroponic plants can be protected from UV radiations, similar to those grown in a protected structure. 11) Production vegetable in off season is possible in hydroponics when market prices are highest (Manzocco *et al.*, 2011). 12) Vertical space can be utilized which is not possible in tradition farming. 13)Higher yield can be obtained by making the system economically feasible in high-density and expensive land areas (Sharma *et al.*, 2018). 14) This system is suitable for the urban areas due to problem of less space, water etc.15) Due to the increase of population in urban cities day by days.

Disadvantages of hydroponics

Despite, hydroponics has numerous advantages over traditional agriculture, it also has limitations: 1) Initial and operational costs are higher than soil culture due to the high cost of required raw materials and equipment for the operation (Souza *et al.*, 2019). 2)Some diseases (water moulds) can spread quickly through the system because each plant in hydroponics system is sharing the exact same nutrient solution (Ikeda *et al*., 2002). 3) To achieve highest yields in commercial agriculture, growers must have the necessary skills and knowledge (Pomoni *et al.*, 2023). 4) The growers must have knowledge of controlling the climatic conditions inside the structure, plant physiology, chemistry and sophisticated control and information systems. 5) Plants respond fast to environmental changes. However, if the change is negative, they may exhibit signs of insufficiency or problems. 6) Energy inputs are required to operate the system (Vourdoubas, 2015). 7) Improper disposal of residual fertilizers which are enriched with phosphorus and nitrates, can generate excessive growth of algae and other microorganisms in water bodies and effluents, leads to developing serious environmental problems (Velazquez *et al*., 2022).

Growing media

A growing media is a physical medium that provides support in the roots of plants and kept them under good growing conditions by providing an aseptic environment with good oxygen and an adequate flow of the nutrient solution. The growing media which is suitable for using in hydroponics system should have following characteristics: 1) Porosity impacts the availability of nutrients for various processes of plant such as respiration, transpiration and photosynthesis, 2) Capillarity; the substrate absorbs nutrients through capillary action and transports them to the roots of plant, 3) Aeration; media should allow the roots for uptake of oxygen when the roots are suspended in the water 4) Non-reactive; Media should not react with other chemicals present in the nutrient solution, means it should be inert, ensuring its composition remains unchanged. 5) Neutral; solution which is circulated in hydroponic system can spread diseases easily if not addressed immediately. Media should not promote bioactivity, as microorganisms can negatively impact crops, causing issues like disease, malnutrition, and other problems (Patil *et al.*, 2020).

Cocopeat/ Coir

It is the byproduct of coconut husk. Residual material left after the removal of fibres from outer layer of coconut called cocopeat. Cocopeat is derived from living tissue which is a 100% ecofriendly substrate. It has highest water absorption capacity, at higher temperature it also acts as buffer and provide aeration to heavy feeder plants (Sharma *et al.*, 2018).

Rock wool

It is the most commonly used media in hydroponics and also called as mineral wool. Basalt and limestone mixture is melted at 1600^0C temperature to prepare rockwool. Rotate this moulted material in high speed to develop thin fibres of 0.005 mm diameter, then give treatment with resin as supplement to bond the fibres, after that compress these pieces into different sizes. Rockwool has high drainage capacity and air circulation.

Perlite

Perlite originated from volcano of grey white silicate material, with neutral pH, that enlarges 4 - 20 times of its original weight when rapidly heated at temperature 1600-1700° F. This expansion occurs because the rock with crude perlite consists 2-6 percent mixed water, which causes it to puff. Every particle surface consists tiny pockets, creating a wide surface area that enables in moisture and nutrients retention and providing them to the roots of plant. Additionally, the particle shape creates air passages, ensuring optimal air circulation and water infiltration capacity. Sterilization of perlite will provide crop free from diseases and insects.

Vermiculite

It is made up of talc. Vermiculite is produced by heating to high temperature i.e. 745 °C leads to expansion of the particles which is having high water holding capacity, good aeration and infiltration. It is good supplier of potassium and magnesium and also provide excellent exchange and buffering capacities (Sharma *et al.*, 2018).

Sand

Most commonly used substrate in hydroponics system is sand. It is cheap and easily available media. The particle size of the sand is 0.05–2.0 mm. The major disadvantage of sand is that, it is very heavy, with poor infiltration and must be used after sterilization.

Nutrients management in hydroponics

17 essential elements are required for the vegetative and reproductive growth of the plants and these nutrients are provided to plants by nutrient solution except carbon, hydrogen, and oxygen, which are air borne. Highly soluble salts are used to prepare nutrient solution however, some inorganic acids are also used (Ramazzotti *et al.*, 2013). Nutrients are divided into two categories: macro and micro or trace elements. Macro nutrients are again divided into two groups primary and secondary elements. Primary elements include nitrogen, phosphorus and potassium whereas, secondary elements include calcium, magnesium and sulphur. Microelements are iron, manganese, copper, zinc, boron, chlorine, molybdenum, nickel. There is various source of nutrients along with their characteristics (Table 1).

Electrical conductivity (EC) and pH management

pH and EC are essential components of the nutrient solution which should be maintained properly for optimum growth of the plant. Nutrients in hydroponic solution should be decided according to crop and their development stages. There are some soluble fertilizers which are used in hydronics system are calcium nitrate Ca $(NO_3)_2$, ammonium nitrate (NH_4NO_3) etc (Ramazzotti *et al.*, 2013). These compositions can be easily prepared from the combination of different salts, fertilizer and minerals, even though also present in different forms like solid form (Velazquez *et al.*, 2022). Table 2 shows EC and pH values ranges for hydroponically grown crops.

Electrical conductivity (EC) of a solution is estimated by measuring the amount of ions concentration. In the hydroponics, ideal EC for maximum crops should range from 1.5-2.5 dS m^{-1}. Greater value of electrical conductivity will result in higher osmotic potential and leads to prevent absorption of the nutrients (Gruda, 2009). On the other hand, low EC means lack of nutrients in the solution (Savvas and Gruda, 2018). Growth and yield of crop will deteriorate so that, EC should be maintained with in optimum range (Swain *et al.*, 2021). In

Table 1 : Sources of nutrients and their characteristics (Sardare and Admane, 2013)

Components	Source	Properties
B	Boric acid (H_3BO_3)	Good source of boron
N, K	Potassium nitrate (KNO3)	Very soluble salts
Na, Ca	Calcium nitrate Ca (NO_3)2	Highly soluble salts
S, Mg	Magnesium sulfate ($MgSO_4$)	Low cost, pure substance and very soluble
P, K	Potassium phosphate monobasic (KH_2PO_4)	Applied at the time of phosphorus deficiency
Fe	Iron chelates	Good source of iron

Table 2 : Ranges of EC and pH several hydroponic crops (Sardare and Admane, 2013).

Crops	EC (dSm^{-1})	pH
Asparagus	1.4-1.8	6.0-6.8
Broccoli	2.8–3.5	6–6.8
Cabbage	2.5–3	6.5–7
Celery	1.8–2.4	6.5
Cucumber	1.7–2	7–2
Eggplant	2.5–3.5	6
Leek	1.4–1.8	6.5–7
Lettuce	1.2–1.	6–7
Okra	2–2.4	6.5
Peppers	0.8–1.8	5.5–6
Spinach	1.8–2.3	6–7
Tomato	2–4	6–6.5

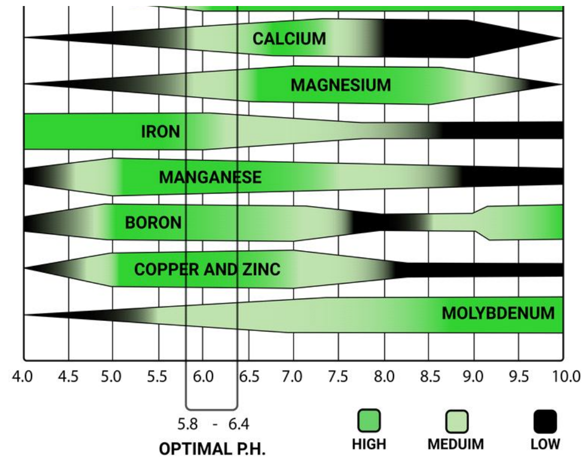

Fig. 2 : pH effect on availability of nutrients (Khaidem *et al.*, 2018).

Table 3 : Different methods of sterilization of nutrient solution used in hydroponic system (Ehret *et al.*, 2001).

Methods	Merits	Demerits
Filtration		
Sand Filters	Low cost, easy to use	More space requirements, pathogen-specific variations in efficacy
Membrane	More effective, require high initial cost investment	Regular water infiltration and stagnation, high maintenance costs
Heat treatment		
Pasteurization	Very efficient, no precipitates are produced	More capital costs, more maintenance costs
Radiation		
UV Radiation	Excellent efficacy (turbidity-free), require less space	Efficiency is very low due to presence of turbidity, expensive equipments are required for precipitation of Mn and Fe
Chemical treatment		
Ozone	More effective	More capital expenses, high maintenance expenditures, high organic matter levels can reduce efficiency when combined with certain micronutrients.
Hydrogen peroxide	Useful for cleaning irrigation systems	When the dose exceeds 0.05%, it harms plant roots.
Chlorine	Cost-effective technique.	Its efficiency is determined by a variety of parameters, including temperature, pH, organic load, and ammonium level. Toxic residues might be created owing to the interaction with organic and inorganic constituents of the nutritional solution.

Table 4 : Some vegetable crops grown under hydroponic system (Zarate, 2014).

Type	Common Name	Scientific Name	Cultivation Technique
Bulb Vegetables	Garlic Onion	*Allium sativum* *Allium cepa*	Drip irrigation NFT, Drip irrigation
Inflorescent Vegetables	Broccoli Cauliflower	*Brassica oleracea* var. *Italica* *Brassica oleracea* var. *botrytis*	Drip irrigation, NFT Drip irrigation, NFT
Leafy Vegetables	Lettuce Cabbage Brussels sprouts Spinach Parsley Coriander	*Lactuca sativa* *Brassica oleracea* var. *capitata* *Brassica oleracea* var. *gemmifera* *Spinacea oleracea* *Petroselinum crispum* *Coriandrum sativum*	NFT, DWC NFT, DWC NFT, DWC NFT, DWC NFT, DWC NFT, DWC, drip irrigation
Root Vegetables	Beetroot Turnip Radish Carrot	*Beta vulgaris* *Brassica rapa* *Raphanus sativus* *Daucus carota*	Drip irrigation, aeroponics NFT Drip irrigation, aeroponics Drip irrigation, aeroponics
Fruit Vegetables	Tomato Eggplant Cucumber Watermelon	*Solanum lycopersicum* *Solanum melongena* *Cucumis sativus* *Citrullus vulgaris*	Drip irrigation, NFT Drip irrigation Drip irrigation, NFT Drip irrigation

hydroponics system, management of EC is adequate tool for the improvement of plants growth, quality and yield. According to Zhang *et al.* (2016), production of tomato was increased by increasing solution electrical conductivity from 0 to 3 dSm^{-1} and further increase of EC will result in decrease of tomato production.

pH determines the presence of essential elements of plants in nutrient solution (Fig. 2). For proper growth and development of plant, the optimum pH should range from 5.5 to 6.5 for most of the crops (Trejo *et al.*, 2012). Scale of pH meter is from 1 to 14 used to identify either the solution is acidic or basic. If, the pH of solution < 7 means solution is acidic and > 7 means basic. Whereas, at pH 7 solution is neutral. In hydroponic system, the optimum pH in which nutrients remain soluble is from 5 to 7 (Kumar *et al.*, 2021). If pH of nutrient solution is higher than 7, it leads to decrease solubility of Fe and H_2PO^{-4}, give rise to precipitates of Ca and Mg and hindering the uptake of B, Fe, Cu, Zn and Mn. However, when pH is < 5, it will reduce uptake of N, P, K, Ca, Mg and Mo.

Nutrient solution sterilization

To maintain aseptic environment in the root zone is essential for good plant growth under soilless culture. it is highly difficult to maintain sterile environment around plant's roots (Raviv *et al.*, 1998). In hydroponics most commonly occurring disease is wilt, caused by Fusarium and Verticillium whereas, other species Pythium and Phytophthora mainly affect roots and destroy whole plant. There is no effective fungicide which can be used safely in this system (Savvas and Passam, 2002). Recycling nutrient solutions plays a crucial role in sustainability by minimizing water usage and management of waste; however, it isn't always feasible to create structure that effectively stabilize usage of economic expenses and power. Table 3 summarized different strategies for sterilization of nutrient solution.

Vegetables suitable for hydroponic system

Variety of vegetables, fruits and other crops can be grown in the hydroponic system. But there are some standards by which we can select particular crop like annual or biennial, vigour of plant, fruit size, root size and harvest duration, commercial value *etc.* List of different vegetable crops is shown in Tables 4 and 5 represent the case studies by different authors.

Future prospects

Hydroponics is recent technique which open "new" door of science for more production of fruit, vegetable and ornamental and also produce high quality products (Putra and Yuliando, 2015). It is the fastest growing technique in horticulture sector and in future for production of food it could very well dominate (Butler and Oebker, 2006). Arable land is decreasing due to the increase of population so people will change to new technologies like hydroponics, aeroponics and vertical farming. By using hydroponics system, we can grow crops like leafy vegetables or flowers in the crowded areas. To understand the future of hydroponics, we can

Table 5 : Case studies on vegetable crops grown under hydroponics.

Crop	Type of research problem	Types of hydroponics system used	Effect/influence on production performance	Source
Cucumber	Evaluation of substrates for cucumber production in the Dutch bucket hydroponic system	Dutch bucket hydroponic system with different substrates (sphagnum peat, medium grade pine bark (Bark-M), coarse grade pine bark (Bark-C), coir and wood fiber).	Cucumber yields and quality was higher in organic substrates as compare to perlite.	Yang *et al.* (2023)
Lettuce	The effect of hydroponics systems on the growth of lettuce	Nutrient Film Technique System (NFT), Deep Film Technique System (DFT), Ebb and Flow Systems (EFS), Aeroponic Systems (AS), and Floating Raft System (RFS).	The NFT hydroponic system improves lettuce yield by 6%-10% (more efficient).	Frasetya *et al.* (2021)
	Variety-specific responses of lettuce grown in a gravel-film technique closed hydroponic system to N supply on yield, morphology, phytochemicals,mineral content and safety	Closed hydroponic system with three lettuce varieties (two green leafy lettuce, Multigreen 1 and Multigreen 3; one red leafy lettuce, Multired 4).	Variety multigreen 3 showed higher fresh leaf weight while the red lettuce (Multired 4) showed highest ascorbic acid content.	Mampholo *et al.* (2018)
Tomato	Water and fertilizers use efficiency in two hydroponic systems for tomato production	Closed hydroponic system (with nutrient solution recirculation) and open hydroponic system (with non-recirculating nutrient solution).	In the closed system 13.50 kg/m^3 more fruit was produced and higher water and fertilizers use efficiency then the open system.	Rosa-Rodriguez *et al.* (2020)
	Effects of hydroponic systems on yield, water productivity and stomatal gas exchange of greenhouse tomato cultivars	Open and close hydroponic system with two cultivars (V4-22 and Amira)	The highest crop yield was found in cultivar V4-22 (3874.29 g per plant Saving of water and fertilizer without a significant effect on crop yield was higher in the closed hydroponic system.	Fayezizadeh *et al.* (2021)
Spinach	Yield and quality attributes of lettuce and spinach grown in different hydroponic systems	Two systems (circulated nutrient film technique (NFT) system and non-circulated system) compared with conventional open field condition.	Higher spinach yield (190%) was observed in NFT.	Acharya *et al.* (2021)
	Effects of different hydroponics systems and growing media on physiological parameters of Spinach	NFT system with different growing media (sawdust, coco peat and sterilized absorbent cotton)	The result showed that all physiological parameter (leaf length, leaf width, leaf area) values were recorded highest from plants grown in sawdust.	Gaikwad *et al.* (2020)

look at some of the pioneers in this field (Singh and Singh, 2012). In Tokyo, land is highly valuable because of the increasing population. To provide food for the residents while conserving precious land, the nation has embraced hydroponic rice farming (Jan *et al.*, 2020). For sustainable production of agricultural crops, hydroponics system gives the ray of hope. Israel has dry and arid climate, by using hydroponic system they grow large quantities of berries, citrus fruits and bananas. It can be profitable technique to grow various vegetables in adverse environmental conditions *viz.,* hilly, arid and cool area. In the developing and developed countries, demand of hydroponic system is increasing day by day. So, government should make public policies and give subsidies for such production systems.

Conclusion

Hydroponics is growing exponentially through world wide and offers various new scopes for both producer and buyer to produce and buy high yield with quality products. Soilless cultivation can be done in small places, short time and with less labour, so this is the greatest opportunity for people of urban cities. It also leads to enhance economic growth and to improve lifestyle of people. It is essential to develop low-cost hydroponic system that helps to lower the operational cost and encourage people for commercial hydroponic farming.

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