__Review Article__

Current hydroponic/aquaponics trends in horticultural crops: Review

Abstract

Currently, hydroponics, a soilless production method, promises to deliver high quality, nutritious, fresh, residue-free crops, overcoming the problems of climate change, freshwater shortage, necessity of fertile land, and the overwhelming requirement of the expanding food demand. Hydroponics production is now garnering prominence across the world because of its effective resource management and cultivation of high value crops. Developed nations like Netherlands, Australia, France, England, Israel, Canada, and the United States are among the world leaders in hydroponic innovation/cultivation. Certain advantages of this technology include shorter crop growth times than traditional crop soil-based, year-round output, low disease, and insect attack, and removal of several labour-intensive intercultural procedures such as weeding, spraying and watering. Nutrient film technique has been successfully employed in the large-scale cultivation of leafy and other vegetables across the world with water savings of 70 to 90%. Commercial hydroponic technology must be successfully implemented, thus it's essential to devise low-cost methods that seem to be simple to use and sustain, need less manpower altogether, and have reduced installation and function costs. Therefore, hydroponics could represent a superior approach to grow various fruits, vegetables, and livestock feed in addition to fulfil the upcoming need for world nutrition.

Keywords- Hydroponics, NFT, soil-less, water, media.

Introduction

By 2050, the world's population is expected to reach 9.7 billion. At the same moment, it is anticipated that half of the world's arable land will become unfit for farming (Bruinsma *et al.,* 2017). To avoid a scenario like this, agricultural techniques must be modernized, and food supplies should be utilized appropriately (Singh *et al.,* 2019). Existing agricultural techniques are essentially reliant on soil and water and are vulnerable to loss due to variable weather conditions; thus, there is a need to reform and enhance economic strategies existing agricultural methods. To accommodate for the concurrent growth in demand for food, agricultural production will need to be doubled. Soil is generally the most ideal or readily accessible medium for crop growth. For successful crop growth, soil offers nutrients, air, water, and other components (Ellis *et al.,* 1974). The inclusion of microorganisms and nematodes is causing the disease, improper soil response, poor drainage, and compaction, soil degradation, and so forth are the major restrictions on soil for successful crop growth (Beibel *et al.,* 1960). Crops grown in towers could reduce the demand for additional land. Protected cultivation can result in higher yields and more effective utilization of inputs (water, fertilizer, and herbicides). The effective usage of natural light is a major benefit of hydroponic greenhouse cultivation. Fruit development is aided by the presence of light. Light falls equally on the top and bottom parts of the plant in a hydroponic greenhouse. Both top and the bottom fruit develop at the same time due to the equal dispersion of light (Despommier *et al.,* 2010).

Hydroponics

The term 'Hydroponics' was derived from the Greek word 'hydro' which means water and 'ponos' means labor (Beibel *et al.,* 1960). Dr. Gericke, a California professor, initiated the term in 1929 a California scientist who began to expand what had earlier been a laboratory technique for producing crops (Stein *et al.,* 2014). Hydroponic farming had a growth in 1990, with applications including space programmes, growing plants in deserts, vertical farming, and large-scale production (Stein *et al.,* 2021). Hydroponics is a modern agriculture technique that uses nutrient solutions rather than soil for crop production (Khan *et al.,* 2020). In today's agriculture, hydroponic farming is a prominent concept. It is simple and easy to understand, and it contributes to water and land sustainability. Hydroponics is defined by Maharana *et al.,* (2011) as a process for growing plants in soil-free conditions with their roots submerged in the nutrient solution. Hydroponics, according to Savaas *et al.,* (2003), is the growing of plants without the use of soil. As a result, it is evident that plants in hydroponics are grown without soil and receive nutrients through a nutrient solution mixed into the water. Generally, hydroponics refers to a subset of plant cultivation methods that do not require the use of soil and instead rely on liquid nutrition solutions (Richa *et al.,* 2020). Traditional farming has dealt with hoeing, hauling, pesticides, the environment, and a variety of different issues. In soil-based horticultural farming, some soil-based crop diseases exist. It also needs a large amount of land utilization (Kori *et al.,* 2021). For a variety of factors, hydroponic culture has remained popular. To begin with, there is no requirement for soil, and a big plant population may be cultivated in a very tiny space. Moreover, when properly fed, maximum output can be achieved. Finally, nutrients, water, and aeration can all be precisely managed.

In solid media, this degree of control is difficult to replicate. Hydroponics allows for the cultivation of a wide range of crops. The yield, taste, and nutritional value of crops grown hydroponically are often superior to those grown naturally in soil (Jan *et al.,* 2020). Hydroponics is now a well-established discipline of agricultural research (Fruscella *et al.*, 2021). Hydroponic greenhouse technologies are regarded to be better than field production methods in aspects of water and nutrient efficiency (Zimmermann *et al.,* 2020). The productivity of a hydroponics-based system, on the other hand, is highly dependent on its layout and how water and nutrient solutions are regulated. Since the discharged solution may be simply recovered for reuse, hydroponic systems are perfect for reusing water and nutrients. Greenhouse vegetables cultivated in closed hydroponic systems can significantly decrease water pollution while also lowering irrigation and fertilizer use (Khan *et al.*, 2020). In deserts, arid plains, mountainous regions, city rooftops, and concrete schoolyards, hydroponic technology efficiently produces crops. Agriculture, like manufacturing, should use technological improvements to provide inventive alternatives to recurring difficulties. Hydroponics is a high-yielding crop that can be automated. Plant factories offer far more tightly regulated settings than greenhouses, where the soil is substituted with non-soil components and nutrients are derived from water-rich nutrients (Kuncoro *et al.,* 2021).

Components of hydroponics

Light

Light is a key component that affects plant growth by influencing photosynthesis, photorespiration, and photoperiodism. For most greenhouse vegetable crops, the optimal light intensity is between 50000 and 70000 lux (Puengsungwan *et al.,* 2020). The availability of nutrients, water, CO2, light, and temperature all affect the process of photosynthesis (Sarath Kumar *et al.,* 2021). On clear summer days, the greenhouse crops were exposed to light intensities ranging from 100,000 lux to 3200 lux on cloudy winter days. None of the extreme situations were suitable for most crops, and many of them were light-saturated. In other words, with light intensity below 32300 lux, the rate of photosynthesis did not rise (Khan *et al.,* 2020). Crop growth and quality can be improved through the use of light quality optimization. To explore the effect of light quality on lettuce development and quality, Li *et al.,* (2021) exposed lettuce seedlings to various light-emitting diode (LED) lights, including red-blue (RB), red-blue-green (RBG), red-blue-purple (RBP), and red-blue-far-red (RBF) LED lights. Due to the reduction in the effective photon flux density for chlorophyll absorption, the fresh weight and dry weight of aboveground lettuce under the RBG, RBP, and RBF treatments were substantially less than those under the RB treatment. Kim *et al.,* (2021) conducted another investigation on lettuce (*Lactuca indica* L. cv. 'Sunhyang') in DFT hydroponics at 14 days after planting, and the results showed that the photosynthetic r ate, stomatal conductance, and transpiration rate of Indian lettuce raised as the light intensity increased.

Relative humidity

Regulating relative humidity within the greenhouse is essential since it affects plant quality. For majority of crops, the standard relative humidity (RH) is 60-75 % (Khammayom *et al.,* 2022). Normal plant growth occurs at relative humidity levels of 25 to 80%, and growth is proportional to relative humidity. However, because most pathogenic spores grow at high relative humidity, too high relative humidity can be hazardous to plants (Xu *et al.,* 2016).

Carbon dioxide

One of the most important environmental elements is CO concentration. In the light-independent process, a rise in CO2 concentration increases the rate at which carbon is incorporated into carbohydrates, hence the rate of photosynthesis normally increases until it is constrained by another variable (Daneshvar *et al.*, 2022). As a result, it can be stated that CO2 concentration is related to photosynthetic rate (Voutsinos *et al.,* 2021).

Water

In the case of hydroponics Reverse osmosis (RO) water with no to low total dissolved salts (TDS) is employed so that salts can be introduced depending on the crop and plant stage (Suwaileh *et al.,* 2020). Treatment of wastewater has recently been employed in hydroponics as a technique of minimizing pollutants in the environment (Khan *et al.,* 2020). Yang *et al.,* (2015) investigated the efficacy of a hydroponic system that cultivated water spinach to polish urine after partial nutrient recovery in order to meet sewer discharge standards and found that plants grown in urine with a 1:50 dilution ratio have equivalent growth properties to those grown in nutrient solution (e.g., growth rate, leaf number, etc.). Magwaza *et al.,* (2020) reported that though wastewater comprises micro and macronutrients; a lack of information about the proper addition of nutrients can restrict plant growth owing to nutritional abundance or deficiency.

Table 1. Some instances of hydroponics experiments using recycled water, including the type of water, hydroponic system, and crops used.

Type of wastewater	Type of crop	Type of hydroponics system	References
Domestic	Lettuce	Nutrient film technique	Carvalho *et al.,* (2018).
Brewery wastewater	*Typha latifola*	Gravel bed	Gebeyehu *et al.,* (2018).
Brewery wastewater	Vetiver grass	Floating raft	Worku *et al.,* (2018).
Domestic	Tomato	Media bed based	Magwaza *et al.,* (2020).
Urban	Tomato	water culture hydroponic system	Anton *et al.,* (2021).
Domestic wastewater	-	water culture hydroponic system	Sundar *et al.,* (2021).

Nutrients

One of the fundamental concepts of vegetable production, both in soil and in hydroponic systems, is to deliver all of the nutrients required by the plant (Hamza *et al.,* 2022). The hydroponic nutrient solution needs to provide water, oxygen, and vital mineral elements to the plant roots in soluble form (Abu *et al.,* 2021). Plants require seventeen elements in order to grow properly. Carbon (C), Hydrogen (H), Oxygen (O2), Sulfur (S), Phosphorus (P), Calcium (Ca), Magnesium (Mg), Potassium (K), and Nitrogen (N) are nine macronutrients that are required in high quantity for plant growth. Iron (Fe), Zinc (Zn), Copper (Cu), Manganese (Mn), Boron (B), Chlorine (Cl), Cobalt (Co), and Molybdenum (Mo) are the other eight macronutrients that are required in modest quantities (Patel *et al.,* 2020). Khodijah *et al.,* (2021) studied different concentrations of NPK + Gandasil while using chicken feather waste on lettuce by employing the simple wick system, and found that while the type of nutrient media composition had no influence on plant height, it did have a substantial effect on leaf length. In another study, Kaur *et al.,* (2018) studied different ratios of nitrogen and potassium in tomatoes and their results showed that the wicked system produced higher fruit yield and better-quality sugars in winter crops with a solution containing N and K in the ratio of 1.4:3 at vegetative and 1.7:3.5 at reproductive stage.

Media

An effective culture media must be able to provide the plant with the maximum amount of available water (high water retention capacity), while also providing adequate aeration to the roots (Cascone *et al.,* 2021). In other words, there should be a good balance between microporosity (consisting of pores capable of retaining water after complete saturation at the end of drainage) and macroporosity (porosity-free, consisting of all pores that do not retain water and are filled with air) (Khan *et al.*, 2020). Various organic and inorganic substrates suitable for crop cultivation were investigated. Jagtap *et al.,* (2022) demonstrated that vegetables may be grown without soil, in containers with water, or on low-cost natural substrates such as sand, rice hulls, pumice stone, and so on. In greenhouse and hydroponic agriculture, new advanced root zone substrates are now being tested as an alternative for natural soils. These media should give a better-rooting environment and anchoring for the root system, as well as provide water and nutrients to the plants and provide an appropriate aeration atmosphere for the roots (Indu *et al.,* 2021). According to Gruda *et al.,* (2019) most commercial greenhouse medium for container crop production, contains 30 to 60% peat moss, either alone or combined with decomposed pine bark. Other minerals like vermiculite and perlite are used to aid with water retention and aeration. Subramani *et al.,* (2022) studied different combinations of cocopeat, vermiculite, cocopeat, perlite, sand, and sawdust on tomato hybrid ‘Arka Rakshak’. The results showed that among the various growth media, cocopeat + saw dust (1:1 v/v) yielded the highest fruits per plant (12.33), fruit weight (51.2 g/fruit), and fruit yield (631 g/plant), and was comparable to coco peat + vermiculite + sawdust (1:1:2).

Temperature

Chemical reaction and physical characteristics of the plant are influenced by the varied level of temperature (Maucieri *et al.,* 2019). The key environmental factor that influences vegetative growth, cluster development, fruit setting, fruit development, fruit ripening, and fruit quality is air temperature (Jiang *et al.,* 2020). The growth is assumed to be caused by the mean 24-hour temperature. It is also regarded that the larger the difference in day-night air temperature, the taller the plant and the smaller the leaf size (Grant *et al.,* 2020). Low temperatures have a direct impact on the organoleptic qualities of vegetables. Tomatoes with less juice and a mealy flavour are a certain sign of low temperature (Gruda *et al.*, 2020).

Tomato, cucumber, and eggplant fruits change shape, colour, and texture when exposed to high temperatures (Rouphael *et al.,* 2018).

Various techniques for hydroponics

In hydroponics, there are various techniques of production. Some of the methods employed by hydroponics are listed below.

Nutrient film technique (NFT) systems

The nutrient film technique was invented during the late 1960s by Dr. Allan Cooper at the Glasshouse Crops Research Institute in Littlehampton, England (Winsor, 1979). Plants are cultivated in gullies in the NFT system, where nutrient solution is circulated across the reservoir. The thin film of nutrient solution keeps the plant roots moistened. The bottom of the roots should ideally be exposed to the nutritional solution. It is comparable to a stream that provides dissolved nutrients to the line. This technique uses a pump to provide nutrients to the plants on a continuous basis, eliminating the need for a timer (Swain *et al.,* 2021).

Deep flow technique (DFT)-pipe system

The nutrient solution runs 2-3cm deep across 10cm PVC pipes in DFT (Swain *et al.,* 2021). Plastic pots hold planting materials, and their bottoms come into contact with the nutrient solution flowing through the pipes. Potted plants are placed in a single plane or in a zigzag pattern (Van *et al.*, 2019).

Drip systems

The drip system which is commonly employed to cultivate long term crops such as cucumbers, tomatoes, peppers, onions, and so on (Waiba *et al.,* 2020). Nutrient solutions are delivered to plants using drip emitters. These timed emitters are set to operate for around 10 minutes every hour, based on the plant's stage of development and the intensity of light accessible. The drip cycle flushes the growing media, providing fresh nutrients, water, and oxygen to the plants (Khan *et al.,* 2020).

Ebb and flow method

This system operates on the flood and drain concept. In this method, the nutrient solution is pumped from a reservoir into the growth medium, flooding it for a brief period of time, and then the nutrient solution is flowed back into the reservoir (Suryaningprang *et al.,* 2021). This nutrient solution outflow from the growth media drives air into the rooted bed, providing a supply of O2. Plants can acquire water and nutritional components from the moistened rooting media (Balliu *et al.*, 2021). The threat of root rot, algae, and mould is particularly frequent in this system, hence a modified system with a filtration unit is necessary (Lee *et al.*, 2015).

Aquaponics systems

Aquaponics is the combination of fish farming with hydroponic cultivation (Lennard *et al.*, 2019). The nutrient-rich wastewater of the fish tanks is delivered via plant growth beds. The maintenance of a thriving bacteria population is essential to aquaponics (Kumar *et al.*, 2020). Beneficial bacteria that naturally reside in soil, air, and water change ammonia to nitrate, which plants quickly absorb (Yep *et al.*, 2019).

Aeroponics systems

Aeroponics is a technique of growing plants that are stranded in the air with their roots, while nutrients and moisture are delivered in the form of a mist (Mangaiyarkarasi, 2020). A timer guarantees that the pump sprays a mist (water) every few minutes. The pump, like the nutrient film approach, must constantly be operational since even a little stoppage might lead the roots to dry up (Fathallah *et al.*, 2022). Aeroponics cultivation is typically conducted in a protected structure and is appropriate for low leafy vegetables such as lettuce, spinach, and so on (Sharma *et al.*, 2018).

Table 2. Recent applications of hydroponics systems in different horticultural crops.

Crops	Scientific name	Cultivar	Substrate	Hydroponic technique	References
Basil and peppermint	*Ocimum basilicum* and *Mentha x piperita L*	Genovese	Perlite	hydroponic closed system	Ronga *et al.*, (2018).
Swiss chard	*Beta vulgaris*	Cicla	Sawdust + sand + vermiculite	Elevated tray hydroponics system	Hlophe *et al.*, (2019).
Mustard	*Brassica Juncea*	-	Rockwool + sawdust + coconut coir	water culture hydroponic system	Zailani *et al.*, (2019).

Curled mallows	*Malva verticillata*	-	Potting mix	Drip irrigation	Lee *et al.,* (2020).
Bean	*Phaseolus vulgaris*	Moraleda	-	Nutrient film technique	Neocleous *et al., (*2020).
Lettuce	*Lactuca sativa*	-	-	Nutrient film technique system	Qadeer *et al.*, (2020).
Lettuce	*Lactuca sativa*		Rockwool	modified Floating Hydroponic Technique (THST)	Muharomah *et al.,* (2020).
Tomato	*Solanum lycopersicum*	Arka Rakshak	Coco Peat + vermiculite + coco peat + perlite + sand + sawdust	Media bed based	Subramani *et al.*, (2020).
Strawberry	*Fragaria* × *ananassa* Duch	Festival	Cocosoil + perlite	Drip irrigation system	Antoniou *et al.*, (2021).
Tomato	*Solanum lycopersicum*	Avalantino F1	Rockwool + hemp fibre	Drip irrigation system	Nerlich *et al.*, (2022).

Conclusion

Hydroponic culture is the most efficient crop production technology in today's farming sector, and mostly employed in industrialized and developing nations for agricultural production in a limited area. Growing hydroponically is even possible in regions with moderate/poor soil, such as deserts. It has several advantages such as conserving water, and environmentally friendly technique, but its main disadvantage is the requirement of huge financial investment and specific skills. Hydroponics enables up to 50% quicker growth than soil by delivering consistent and easily available nutrition. However, the popularity of hydroponics has grown substantially in a brief span of time, resulting in a rise in experimentation and research in the field of indoor and outdoor hydroponic production.

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