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Opportunities and constraints in hydroponic crop production systems: A review

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ABSTRACT

Hydroponic crops can be grown using a variety of media and production systems (NFT system, wick system, drip system, ebb flow system etc.). EC and pH management are required to successfully handle these hydroponic systems (water quality and nutrient solution maintenance). These hydroponics systems have gained rapid adoption due to disciplined management of their resources and food production. Although the hydroponic system was developed in a closed-loop system, and substrate nutrition increases production, it is not cost-effective to develop this system on big scale. It is critical to design a low-cost hydroponic structure that decreases reliance on human labour and lowers overall startup cost in order to increase the commercialization of hydroponic farms. We need more research to develop more productive and cost-effective organic nutrient solutions and improve hydroponic crop production systems. In this review paper, we will discuss the opportunity and challenges in hydroponic crop production systems.

Introduction

Food-growing systems must be developed in order to feed the world's rising population in a sustainable manner. For feasible production and conservation of rapidly decreasing land and water supply resources, changing the growth medium is a possibility. Soilless farming is currently a realistic option for cultivating healthy edible plants, crops, or vegetables that may be properly introduced and evaluated (Butler and Oebker, 2006). In addition to substrate culture, farming without soil includes hydroponics, aquaponics, and aeroponics. These hydroponics systems have gained rapid adoption due to disciplined management of their resources and food production (Hussain *et al.,* 2014). Hydroponics may be used to produce a wide range of marketable and regional crops, including tomatoes, peppers, cucumbers, strawberries, and green vegetables. Lettuce and spinach are the most promising species to grow in aquaculture and hydroponics systems because of their high growth and nutrient uptake ability (Sharma *et al.,* 2018).
Hydroponics is a technique for growing plants without soil by immersing their roots in a nutrient solution. This approach aids in addressing the difficulties of climate change and production system management in order to reduce malnutrition and make effective use of natural resources (Hussain *et al*., 2014). Aeroponics technology is similar to hydroponics in many ways, with the exception that plants in aeroponics are grown with thin droplets of nutrient solution (a mist or aerosol). W J Shalto Duglas, an English scientist who constructed a laboratory in the Kalimpong district of West Bengal and produced the book "Hydroponics: The Bengal system," recognized hydroponics in India in 1946. The term

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hydroponics comes from two Greek words: hydro, which means "water," and ponic, which means "to work." Hydroponics is related to growing plants in soil-less and nutrient-rich solutions to increase the production of crops. The water used for the production of crops should be clean and free from microbial contamination and chemical agents (Suma *et al.,* 2020).

Hydroponic greenhouse systems eliminate the requirement for additional land for crop production. To boost output by reducing water, fertilization, and pesticide use, which can be reached through greenhouse farming? The efficient use of sunlight is a benefit of hydroponic greenhouse farming. Light falls on both the upper and lower parts of the plant in a hydroponic greenhouse. Both top and lower fruits develop at the same time due to the uniform dispersion of light (Despommier, 2009).

Hydroponics farming allows people to grow forage and food in areas where conventional agriculture is not possible, desert-like regions with arid climates (Okemwa, 2015). The hydroponic method allows people to consume and enjoy locally grown products while also increasing their food production. In heavily populated metropolitan areas where there is no suitable land for farming, hydroponics can be used (Schnitzler, 2012). Hydroponic methods are helpful in areas with warm climates or inadequate sunlight (Jensen and Malter, 1995). Hydroponic systems for crop production are rapidly developing and improving nowadays (Griggs *et al.,* 2019).

Historical background of hydroponic

Julius von Sachs, a well-known German botanist, demonstrated for the first time in 1860 that plants could be grown to maturity in the lack of soil using a specific nutritional solution. Professor William Gerrick invented the term hydroponics to describe the growth of plants with roots suspended in water containing necessary nutrients in the early 1930s. In 1940, Purdue University researchers created the feeding system. Hydroponics gardens were established in Arizona, Abu Dhabi, Belgium, California, Denmark, Germany, Holland, Iran, Italy, Japan, and Russia throughout the 1960s and 1970s (Sardare *et al.,* 2013). Due to hasty industrialization and urbanization, not only the cultivable land is diminishing but the conventional farming techniques are also having a significant negative influence on the environment. In present situation, soilless farming can be successfully introduced and considered as an alternative option for growing nutritious food plants, healthy edible vegetables, or crops (Sharma *et al.,* 2018).

Hydroponic structures

Plants cultivated in hydroponic culture have their roots suspended directly in a nutrient solution. So it is also named by Liquid hydroponics system. In this system, plant roots are supported by soil pellets, peat moss, perlite, and rock wool. Hundreds of variations of hydroponic systems are available when we build a hydroponic structure for growing plants. However, here we are discussing five types of hydroponic systems under which all variations are located.

1. Wick System, 2. Drip system, 3. Ebb-Flow, 4. Nutrient Film Technique (NFT)

Wick System

In the wick system, the root of the plant is fed by a strip of porous material that is immersed in a liquid that is fed to the capillary in a tray or other absorbent medium. The system is installed above the feed solution tank at a minimum distance (Grigas *et al.,* 2019). It is the most basic hydroponic system, requiring no pumps, electricity, or aerators (Shrestha and Dunn, 2013). Plants are kept in an absorbent medium such as coco-peat, perlite, or vermiculite, with a nylon wick running through their roots to hold nutrient solution. Capillary action transports water and nutrients to plants. This technique works well for small plants, herbs, and spices, but not for plants that need a lot of water. The tank containing the nutrient solution, the growing container, the growing media, and the wicks are the four essential components of a hydroponic wick system (Sharma *et al.,* 2018).

Drip system

The drip system is a fast-growing hydroponic system nowadays. It contains a pump to feed the plants with nutrients and water regularly. This system is well-known as a micro-irrigation system. This technique employs little hoses to provide nutritional solution or water directly to the root zone of the plant (Palm *et al.*, 2018). This technology has the advantage of using less water and performing well in both soil and hydroponics growing conditions (Grigas *et al.,* 2019).

The drip hydroponic method is the most used method, with the help of a water pump, water or nutrient solution from the tank is directly delivered to the roots of each plant in right proportion (Rouphael and Colla, 2005). Plants are usually planted in a medium that is somewhat absorbent so that the nutrient solution drips down slowly. Various crops can be cultivated organically, with as much water conservation as feasible (Sharma *et al.,* 2018).

Ebb flow system

This was the first commercial hydroponic structure, and it works on the flood and drain method. The fertiliser solution and water from the reservoir rise through a water pump in the floodplain until they reach a specified level and stay there for a set period of time, providing nutrients and moisture to the plants. In addition, it is possible to grow a broad variety of crops, but algae, root rot, and mold problems are very common (Nielsen *et al.,* 2006).

Nutrient film technique (NFT)

NFT was developed by Dr. Allen Cooper in England in the mid-1960s to overcome the shortcomings of the ebb and flow system. A nutrient solution or water circulates throughout the system; and without any time control, the water enters the rising tray by using the pump (Domingues *et al.,* 2012). The system is tilted at an angle, allowing the nutrient solution to flow through the roots and into a reservoir below. The plants' roots are suspended in a hydroponic nutrition solution and placed in a conduit or pipe. The roots, on the other hand, are susceptible to fungal infection because they are constantly submerged in water or nutrients. Many leafy greens can be easily grown in this system, and it is broadly utilized for commercial lettuce production (Sharma *et al.,* 2018). The main quality of this technology is irrigation and the solution of nutrient is recycled several times (Burrage, 1992). This system is usually adapted for various plant growths and is a perfect solution for growing short-cycle plants such as cereals, lettuce, etc. This technique is similar to the ebb and flow methods for numerous reasons. It consists of a recirculation pipeline that allows the conversion of used water or nutrient solution from the reservoir into a container that can be cleaned. Also, these growing systems rely entirely on water pumps to provide solution recirculation and nutrition to the plants (Grigas *et al.,* 2019).

Advantages of hydroponics

There are so many advantages of growing plants under hydroponic system as compared to conventional system. Because the nutrients are given directly to the roots, the plants develop faster and have smaller roots, allowing them to be grown closer together. Hydroponic system provides increased production per acre along with effective nutrient controls, high-density seeding, and improved production quality. It is also efficient for areas of the world where there is a lack of cultivable or fertile land for agriculture (Sardare *et al.,* 2013).

Hydroponic technology is a sparkling and comparatively simple technique and it reduces or eliminates the use of insecticides to reduce or eliminate the possibility of soil-borne diseases, insect or insect infestation to plants. This method is particularly useful in locations where environmental pressure (cold, heat, sweet, and so on) is a significant problem (Polycarpou *et al.,* 2005). Because hydroponic crops are not impacted by weather fluctuations, they can be cultivated all year and considered off-season (Manzocco *et al.,* 2011). Furthermore, commercial hydroponic systems are intended to minimise labour and eliminate many traditional agricultural procedures, such as weeding, spraying, watering, and ploughing, by operating automatically (Jovicich *et al.,* 2004). Hydroponics saves a lot of water in the form of irrigation and doesn't require any other kinds of spray, so there's never any problem of waterlogging. Pests and illnesses may be easily controlled, whilst weeds are virtually non-existent. When compared to conventional farming, larger yields can be attained because to a higher number of plants per unit (Sharma *et al.*, 2018). The hydroponic system uses fewer pesticides, produces more, and saves water (Arias-fermandz *et al.,* 2000; Buchanan *et al*., 2013).

Hydroponic greenhouse systems are the most efficient way to grow high-nutrient-value crops (Jones, 2012). Hydroponic systems have more benefits than drawbacks (Banda-Guzman and Lopez-Salazar, 2014). The percentage of land, nutrients, water requirement, and growing time are low in the case of hydroponic greenhouse systems (Banerjee and Adenauer, 2014). In the case of hydroponic greenhouse systems, plants are never under stress because nutrients and water are always available to the plant roots (Ruth, 2009; Khan *et al.,* 2018).

Limitations of hydroponics

Although soilless farming is an advantageous technique, it has significant limitations. Technical knowledge and high initial cost are the basic requirements for commercial-scale farming. Water-borne diseases can easily spread from one plant to the next in a hydroponics system since the plants share similar nutrient (Ikeda *et al.,* 2006). Hot climate and a lack of oxygen can reduce production and lead to crop loss. The necessity of maintaining the EC, pH, and optimum concentration of the nutritional solution cannot be overstated. Finally, lighting and energy supplies are required to keep the system running in a safe environment (Sharma *et al.,* 2018). Hydroponics is becoming a more popular method of growing vegetables. However, one of the major drawbacks of hydroponics is that certain crops can quickly accumulate large levels of nitrate-N (NO_3± -N) from the system (Guo *et al.,* 2019).

According to Tyson *et al.* (2004) the hydroponic structure's world should be able to support at least 40 large plants (tomatoes, banana peppers, and bell peppers) and 72 little plant (spinach, lettuce, and strawberries). Temperature, light intensity, carbon dioxide concentration, and humidity must all be monitored in hydroponic greenhouses using an Arduino-based climate control monitor system (Hochmuth and Hochmuth, 2001).

Several aspects should be considered during the installation of an Arduino-based climate control system, including (system availability, system efficiency, and transportation cost, among others), and the initial cost of the system is also supported by these elements (Taig, 2012). According to a literature review, the cost of an Arduino-based climate control system for a commercial hydroponic system is between US$500-2000 (Grewal *et al*., 2011; Takakura, 2014; Khan *et al*., 2018; Manju H.M., *et al*., 2020).

Management of nutrients in hydroponic

In hydroponics, due to the low nutrient-buffering capacity of the system and the ability to make quick adjustments, constant monitoring is required. The availability of nutrients from the nutrient delivery system, as well as the response of plants to nutrients, are two aspects of nutrition that must be considered. The optimal time for monitoring the nutritional solution is between 6 am to 8 am. To avoid damage and the spread of diseases, the roots should be mulched instead of the leaves (Sardare *et al.,* 2013). The sources of nutrients along with their characteristics are given in the table 1.

Table 1: Sources of nutrients and their properties (Sardare *et al.,* 2013)

Source	Components	Properties
Calcium nitrate $Ca(NO_3)_2$	Na, Ca	Salt that is very soluble
Boric acid (H_3BO_3)	B	Boron's best source
Iron chelate	Fe Cit	Iron's best source
Potassium nitrate(KNO_3)	N,K	Salts that are very soluble
Potassium phosphate monobasic KH_2PO_4	P,K	Phosphorus deficiency should be evaluated
Magnesium sulfate ($MgSO_4$)	S, Mg	Very cheap, highly soluble, and pure substance.

Electrical conductivity (EC) and pH management

In hydroponics, plant nutrients are dissolved in water and are generally inorganic. Different chemical combinations provide all 17 components required for plant growth. The most prevalent nutrient solution for hydroponic systems is Hoagland's solution (Sharma *et al.,* 2018).

The pH of the water has a major impact on nitrification. The reaction rate of nitrification in a growing biofilter (root growth centre) produced by a solution of hydroponic nutrients, NO_3^- and two pH levels (6.5 and 8.5) were developed by (Tyson *et al.,* 2007). At pH 8.5, the rate of ammonia oxidation increased (1.75) compared to the rate of nitrite oxidation (1.3), resulting in NO_2^- accumulation at values similar to those damaging to plants (high value of 4.2 mg L^{-1} NO_2^-). Another issue associated to pH 8.5 is the potential for increasing quantities of non-ionized ammonia, which lowers nutritional content in rainwater plants (Toshiki Asao, 2012).

Plants adjust electrical conductivity (EC) while they absorb nutrients and water from the nutrient solution. A rise in the EC value has been reported in an open system with nutrient solution recycling due to the accumulation of high amounts of specific ions such as bicarbonate, sulfate, and chloride. (Zekki *et al.,* 1996). So, the recycling of nutrient solutions represents a point of discussion. In addition, substrates can retain ions, and consequently, the EC increases. Controlled leaching with good quality water is an option for reducing salt nutrient solutions for hydroponic systems (Cácere, 2004). Mulching with polypropylene sheets reduces water usage, improves water efficiency, and lowers the EC of the solution; as a result, mulching is a viable method for EC reduction (Farina *et al.,* 2003). Carmassi *et al.,* (2005) established a general model for variations in ion concentration and EC recycling nutrient fluid during a closed-loop soilless culture supported by hydroponically grown plants.

The pH of hydroponic systems changes as the plants develop. As a result, in hydroponic solutions, pH regulation is necessary. pH changes of less than 0.1 units have little effect. Most species benefit from a pH range of 5.5 to 6.5 for nutrient availability from most nutrient solutions, while species vary widely and develop best outside of this range (Sardare and Adamane, 2013). Table 2 shows the appropriate range of EC and pH values for several hydroponic crops.

Table 2: EC (dSm^{-1}) and pH ranges for hydroponic plants (Sardare and Admane, 2013)

Crops	EC (dSm^{-1})	pH
Asparagus	1.4 to 1.8	6.0 to 6.8
Tomato	2.0 to 4.0	6.0 to 6.5
African violet	1.2 to 1.5	6.0 to 7.0
Basil	1.0 to 1.6	5.5 to 6.0
Banana	1.8 to 2.2	5.5 to 6.5
Broccoli	2.8 to 3.5	6.0 to 6.8
Cabbage	2.5 to 3.0	6.5 to 7.0
Cucumber	1.7 to 2.0	5.0 to 5.5
Egg plant	2.5 to 3.5	6.0
Lettuce	1.2 to 1.8	6.0 to 7.0
Peppers	0.8 to 1.8	5.5 to 6.0
Spinach	1.8 to 2.2	6.0 to 7.0

Water use efficiency in hydroponics systems

The drained water collected after irrigation was used to calculate overall water usage. The total amount of water utilised by plants (litres per tray) was estimated (Ningoji *et al.,* 2020).

Total water use = total water delivered to irrigation + total water drained from trays (Hatfield *et al.,* 2001).

According to the below equation (Eq.1.1), water usage efficiency in kg/m^3 was calculated (Manju H.M., *et al*., 2020).

$$We = \frac{Tp}{Tw} \qquad \text{...... (1.1)}$$

Where,

We = Water use efficiency (kg/m^3)
Tp = Total production (kg)
Tw = Total water use (liter)

Future scope of hydroponics

Hydroponics systems are a rapidly growing sector of agriculture, and they can produce food products in the future. People will prefer hydroponics and aeroponics to agricultural cultivation as the population grows and arable land reduces caused by inadequate land management. Because of the city's rising population, land in Tokyo is exceedingly valuable. The government has turned to hydroponic rice farming to feed its growing population while preserving valuable land. Because the environment is totally regulated with hydroponics, four crop cycles can be done annually instead of the typical single crop. In Israel, where the weather is arid, hydroponics has proven to be effective. The procedure is totally automated, with robots operating on assembly line-style systems similar to those found in factories. In Africa and Asia, where both water and food are limited, hydroponics has the potential to feed millions of people. Hydroponics will also play a major role in the space program's future. NASA has large hydroponics exploration efforts that will enable future, long-term habitation of Mars or the Moon, in addition to current space technologies (Sardare *et al.,* 2013). The hydroponic business in India is predicted to grow dramatically in the near future. It is essential to design low-cost hydroponic structures that reduce reliance on human workers and lower overall set-up and operation expenses in order to encourage commercial hydroponic farms (Sharma *et al.,* 2018, Manju *et al.,* 2020). In the future, the goal of organic nutrient work should be to be able to standardize the methods, additions, and results of organic nutrient solutions for small-scale organic farmers. To ensure consumer confidence in organic, foods must be as safe and healthy as conventional alternatives. Hydroponic farming can yield high-quality, efficiently produced veggies for urban and rural farms, as well as for future research beyond Tera Fera, with the right nutrient solutions, temperatures, and other environmental variables (Ferguson *et al.,* 2014).

Conclusion

The hydroponics industry is going to be the fastest-growing industry in the future. In India, the urban concrete empire is growing day by day, adopting soil-less culture to help increase production and quality of the products in order to ensure our country's food security. In hydroponics systems by use of proper nutrient solutions, with controlled temperatures, and environmental conditions, produced high-quality crops. Nowadays seed germination and hydroponic grass production are used for good nutrition. Various seeds grown by hydroponics system can be appropriately used on small farms, for producing high-quality products. Researchers obtained high-quality goods using the hydroponic system, which are likely to fulfil market expectations. Our worry with the soilless cultivation technique reflects a lack of understanding of its advantages, which include a flexible growth approach that gives the grower complete control over the growing conditions, including the active root zone. To assist eco-agriculture, these methods, which can increase the efficiency of water usage while maintaining its quality, should be adopted on a larger scale. We need further research to develop more productive and cost-effective organic nutrient solutions and improve hydroponic crop production systems. To Increase the commercialization of hydroponic systems, it is essential to design low-cost hydroponic structures that reduce reliance on human workers and lower overall set-up and operation expenses in order to encourage commercial hydroponic farms.

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